

For Reference

NOT TO BE TAKEN FROM THIS ROOM

Ex LIBRIS
UNIVERSITATIS
ALBERTAEENSIS



THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR	PAUL J. ENGLISH
TITLE OF THESIS	GOLD-QUARTZ VEINS IN METASEDIMENTS OF THE YELLOWKNIFE SUPERGROUP, NORTHWEST TERRITORIES: A FLUID INCLUSION STUDY
DEGREE FOR WHICH THESIS WAS PRESENTED	MASTER OF SCIENCE
YEAR THIS DEGREE WAS GRANTED	1981

Permission is hereby granted to THE UNIVERSITY OF ALBERTA LIBRARY to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written

THE UNIVERSITY OF ALBERTA

GOLD-QUARTZ VEINS IN METASEDIMENTS OF THE
YELLOWKNIFE SUPERGROUP, NORTHWEST TERRITORIES:
A FLUID INCLUSION STUDY



by

PAUL J. ENGLISH

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

FALL, 1981



Digitized by the Internet Archive
in 2019 with funding from
University of Alberta Libraries

<https://archive.org/details/English1981>

THE UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Gold-Quartz Veins in Metasediments of the Yellowknife Supergroup, Northwest Territories: A Fluid Inclusion Study submitted by Paul J. English in partial fulfilment of the requirements for the degree of Master of Science.

For Kathy

"What is better than gold? Jasper.

What is better than jasper? Wisdom.

And what is better than wisdom? Woman.

And what is better than a good woman? Nothing."

From The Tale of Melibeus, The Canterbury Tales,
Geoffrey Chaucer

ABSTRACT

Samples from twenty gold-quartz vein occurrences in the meta-sediments of the Yellowknife Supergroup, NWT, were collected and of these nine provided material suitable for fluid inclusion study. The inclusions were studied using petrography, microthermometry, crushing experiments and scanning electron microscopy.

Primary fluid inclusions indicate that the original mineralizing fluid had a salinity of about 5 weight percent NaCl equivalent and homogenization temperatures give a minimum temperature of formation of 250-280°C. Homogenization temperatures from veins within medium grade metasedimentary rocks are slightly but distinctly higher than those for the veins in low grade rocks. The mineralizing fluid was a carbon dioxide-rich sodium chloride brine, with a trace amount of methane.

Published oxygen isotope data give a temperature of formation of 360°C. This difference may be accounted for by a pressure correction for a pressure of approximately 1 kbar (100 MPa). However the existence of 2 primary inclusion populations, one CO₂-rich the other H₂O-rich, indicates that "boiling" (unmixing) may have occurred in which case no pressure correction is required to the homogenization temperatures.

The nature of the gold-transporting agent is not known; the hydrothermal fluid contained both chloride and sulphide components. Published experimental studies on gold geochemistry suggest that a combination of decreasing temperature, decreasing pressure and changing oxygen fugacity caused gold deposition.

Secondary inclusions provide information on a later stage hydrothermal fluid of moderate to high salinity ($\sim 10-30$ wt. % NaCl equivalent) and probably low temperature (mean temperature of homogenization $\sim 140^{\circ}\text{C}$); minor gold remobilization occurred during this stage. This fluid was NaCl-rich and contained minor amounts of calcium, carbonate and sulphate.

This study suggests that petrography and microthermometry of fluid inclusions and oxygen isotope analysis of quartz are insufficient to distinguish auriferous quartz veins from barren quartz veins.

The data from this study do not conclusively support either a magmatic-hydrothermal or a metamorphogenic origin for the veins. However considering the data along with accounts of gold mineralization elsewhere in the world leads the author to favour genesis of the mineralization in the late stages of metamorphism through metamorphogenic processes.

ACKNOWLEDGEMENTS

This project was initiated by Drs. R. St. J. Lambert, R. D. Morton and W. Padgham. I am most grateful to Dr. R. D. Morton not only for his supervision of this thesis but also for imparting some of his knowledge of, and enthusiasm for, economic geology. The fieldwork was supported both financially and logistically by the Resident Geologists Office, Department of Indian Affairs and Northern Development, Yellowknife, and I thank Dr. W. Padgham and his staff for their assistance and advice. G. Braybrook operated the scanning electron microscope and Dr. K. Muehlenbachs performed the isotopic analyses. R. Turner provided very capable field assistance. Typing was by Kathy Wintringham. I have benefited from discussions with numerous geologists; I would particularly like to thank Drs. R. D. Morton, B. Nesbitt and G. Walrond, and Messrs. D. Blackadar, S. L. Brame and R. L. Miller. I received financial support in the form of bursaries from the Department of Geology and much of the research was carried out while I was in the employ of the University of Alberta and Athabasca University. No one who studies fluid inclusions can fail to acknowledge the work and publications of Dr. E. Roedder, which have made a realm of information accessible and comprehensible.

Last yet foremost, I would like to thank K. Megli for unending patience and support.

TABLE OF CONTENTS

Chapter		Page
1	INTRODUCTION	1
	Purpose of Study	1
	Background	1
	Methodology.	1
2	GEOLOGY OF THE YELLOWKNIFE DISTRICT.	3
	Regional and Local Geology	3
	Metamorphism	6
	Structural Geology	7
3	GOLD MINERALIZATION IN THE YELLOWKNIFE DISTRICT	9
	Introduction	9
	Description of the Mineralization.	9
	Gold Mineralization in Metavolcanics	9
	Gold Mineralization in Metasediments	10
4	FLUID INCLUSION STUDIES.	14
	4.1 Principles and Previous Work	14
	Introduction	14
	Classification of Inclusions	15
	Composition of the Fluid Inclusions.	15
	Homogenization of Inclusions	16
	Previous Studies of Gold Deposits.	18
	4.2 Type of Inclusions	23
	4.3 Microthermometric Results.	25
	Low Temperature Studies.	26
	High Temperature Studies	29
	4.4 SEM Study.	33
	Results.	34
	4.5 Fluid Inclusions and Mineral Exploration	39
5	OXYGEN ISOTOPE STUDY	44
	Introduction	44
	Background and Methodology	44
	Results and Discussion	45
	Conclusions.	49

Chapter		Page
6	DISCUSSION AND SUMMARY	50
	Origin of the Gold Mineralization.	50
	Source of the Gold	51
	Transport and Deposition of the Gold	53
	Summary.	55
	Conclusions.	56
	BIBLIOGRAPHY	58
APPENDIX I	BRIEF NOTES ON THE GOLD OCCURRENCES STUDIED.	75
APPENDIX II	FLUID INCLUSION METHODOLOGY.	89
APPENDIX III	FLUID INCLUSIONS SALINITY DATA	101
APPENDIX IV	FLUID INCLUSION HOMOGENIZATION DATA.	105

LIST OF TABLES

Table		Page
1	Oxygen Isotope Data for Quartz	46
2	Oxygen Isotope Data; Kerrich and coworkers	48
3	Microthermometry Calibration Standards	93
4	Crushing Data	99

LIST OF FIGURES

Figure		Page
1	Generalized geology of the Slave Province	4
2	Geological sketch map of the Yellowknife-Hearne Lake area, southern Slave Province	12
3	The H ₂ O-NaCl system	17
4	Fluid inclusion types	24
5	Salinity results for primary and secondary inclusions	28
6	Distribution of homogenization temperatures for primary and secondary inclusions	30
7	Distribution of homogenization temperatures for primary inclusions: veins from low grade and from medium grade metasediments	31
8	Location of the AM and Camlaren gold occurrences	76
9	Geological sketch map of the AM occurrence	78
10	Camlaren mine	79
11	Location of the Joon, Ruth and TA occurrences	81
12	Geological sketch map of the Joon occurrence	82
13	Location of the Ptarmigan, Tom, and Tin occurrences	84
14	Microthermometric stage reproducibility	92
15	Calibration curve for the heating stage	95
16	Calibration curve showing correction values	96

LIST OF PLATES

Plate		Page
I	SEM Images of Fluid Inclusions.	36
II	SEM Images of Fluid Inclusions.	38

1. INTRODUCTION

Purpose of Study

The principle aim of this thesis was to carry out a detailed study of the fluid inclusions in quartz of gold veins from meta-sediments of the Yellowknife Supergroup, near Yellowknife, Northwest Territories. This was done with the objective of determining the composition of the hydrothermal fluid and the environment of deposition, and to evaluate the use of fluid inclusions in exploration for such mineralization.

Background

Much work has been published on the gold veins which occur in metavolcanics at Yellowknife (see Boyle 1979) but little information is available for the gold veins in the metasediments. This, along with published reports of the use of fluid inclusions and oxygen isotopes in prospecting for gold-quartz veins, suggested a detailed fluid inclusion study would be worthwhile.

An initial study of the fluid inclusions was performed by Colin Ramsay, but he studied mainly the barren veins of the area and only included two auriferous veins; also he was unable to obtain salinity data (Ramsay 1973). This study was intended to complement his work.

Methodology

Over twenty gold showings were visited and sampled during the summers of 1976 and 1977. Occurrences in both low grade and

medium grade metamorphic rocks were sampled to determine if there were any significant differences between the two groups. Most of the sample material proved to be unsuitable for study--the samples contained abundant fluid inclusions but these were generally too small to work on. Samples from nine separate gold-quartz veins were found to be suitable.

Samples were studied petrographically and then microthermometric and crushing studies were performed on them. Microthermometry was the major part of the research and was carried out using a Chaixmeca heating/freezing stage. In the last fifteen years fluid inclusion research has undergone a resurgence and three different microthermometric stages are now commercially available; the Chaixmeca stage is perhaps the most versatile of these. Details of the calibration and use of this stage are included elsewhere in this thesis.

To supplement the petrographic studies a few samples were also studied using a scanning electron microscope; this was chiefly to provide details of observed daughter minerals.

Limited oxygen isotope analyses were carried out to provide additional temperature information and to evaluate their use in exploration.

2. GEOLOGY OF THE YELLOWKNIFE DISTRICT

Regional and Local Geology

The study area is within the Slave Province, a part of the Canadian Shield which has remained relatively stable since 2.5 Ga ago. The province is underlain by two main lithologies: Archean granitic and supracrustal rocks (see Figure 1).

The supracrustal succession, which has been named the Yellowknife Supergroup (Henderson 1970) consists of thick sequences of mafic volcanic rocks and turbidites variously deformed and metamorphosed (McGlynn and Henderson 1970). This makes it lithologically similar to the supracrustal rocks of most other Archean cratons but it differs in that sedimentary rocks (~80% by volume) greatly exceed volcanic rocks (~20% by volume) (McGlynn and Henderson 1972).

The volcanic component of the Supergroup in the area around Yellowknife has been well documented (Boyle 1961, Baragar 1966, Henderson and Brown 1966, Padgham 1980a) while Lambert (1977) describes the volcanics that form belts along the Cameron and Beaulieu River systems to the northeast of Yellowknife. The volcanic rocks consist mainly of massive and pillowed basaltic flows with relatively minor intermediate and felsic volcanics, extruded about 2.7 to 2.6 Ga ago (Green and Baadsgaard 1971).

The sedimentary sequence of the Supergroup conformably overlies the volcanics and consists principally of voluminous greywacke and mudstone turbidite deposits with minor amounts of conglomerate and lithic sandstone (Henderson 1972, 1975). The

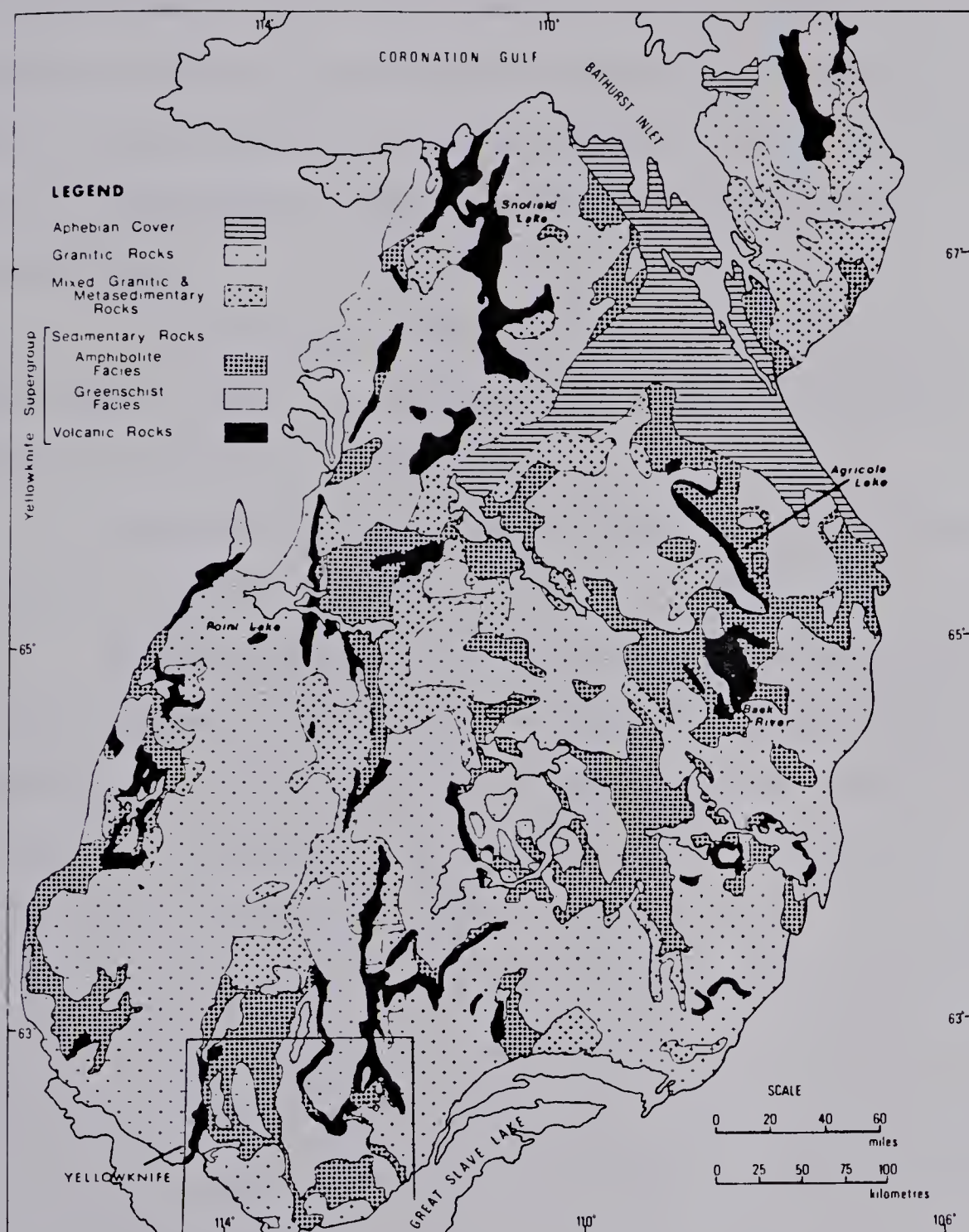


FIGURE 1: Generalized geology of the Slave Province. Area outlined is shown in greater detail in Figure 2. (From Henderson 1977).

Yellowknife-Hearne Lake-Gordon Lake district is a preserved area of supracrustal rocks that has been interpreted as the remnant of a distinct depositional basin separated from other basins by positive areas now represented by areas of granitic rocks (McGlynn and Henderson 1972).

Folinsbee et al. (1968) suggested, by analogy with the Fossa Magna of Japan, that the supracrustal rocks at Yellowknife probably accumulated in about 15 Ma.

The sedimentary rocks are considered to be derived from erosion of an earlier extensive sialic crust.

Granitic rocks underlie about two-thirds of the Slave Province and these can be divided into three categories (McGlynn and Henderson 1972). Firstly, perhaps as much as half of them are gneisses and migmatites that are probably derived from the sedimentary rocks of the Yellowknife Supergroup. Secondly, there is a suite of slightly gneissic rocks that occur as discrete intrusions within the Yellowknife rocks or as large masses between outcrops of the supracrustal strata. These rocks are most commonly granodiorite, quartz diorite and quartz monzonite, and appear to have been mainly emplaced about 2.6 Ga ago (Green and Baadsgaard 1971, Cumming and Tsong 1975).

The third group consists of granitic gneisses and massive plutons very similar to those of the second category but they are distinguished as they are thought to be older than the Yellowknife Supergroup. This is based largely on field geologic evidence (e.g.

Baragar 1966, Davidson 1972, Baragar and McGlynn 1976) and is supported by recent geochronological results. Ages of around 3.0 Ga have been obtained for granitic basement near Indin Lake (Frith, R. et al. 1977) and at Point Lake (R. K. Wanless in Henderson 1977). Also Nikic et al. (1980) have given an age of 3.2 Ga for granitic boulders in a diatreme that intrudes the volcanic rocks at Yellowknife. These boulders are thought to be derived from an underlying sialic basement.

Metamorphism

Although generally referred to by their premetamorphic names the supracrustal rocks were subjected to low pressure regional metamorphism about 2.6 Ga ago (Thompson 1978). Three metamorphic zones have been distinguished: low, medium and high grade (Thompson 1978). These correspond to greenschist, lower amphibolite and upper amphibolite facies respectively. The transition from metagreywacke-slate to knotted schist in the metasedimentary rocks marks the boundary between lower and medium grade, while the transition from knotted schist to gneiss and migmatite marks the boundary between medium and high grade.

Early regional mapping of the province included these three metamorphic zones (e.g. Henderson 1939, 1941a, b, c; Jolliffe 1942, 1946) and they are shown on the compilation of McGlynn (1977). However detailed studies of the metamorphism have only been carried out in limited areas. Ramsay (1973a, b, c, 1974) has documented mineralogical compositions and metamorphic reactions within the

low grade zone in the metagreywackes near Yellowknife. Meanwhile, Kamineneni (1973, 1975) has described the metamorphism of the greywackes to the east of Yellowknife in an area within the medium grade zone.

Mineral assemblages within the lower grade pelitic rocks consist of chlorite, white mica, biotite, plagioclase and quartz. Assemblages in pelitic rocks of the medium grade zone include combinations of biotite, muscovite, cordierite, andalusite, plagioclase and quartz. Garnet occurs sporadically in pelitic rocks at any of the three metamorphic grades (Thompson 1978), and gedrite has been documented in the medium grade zone (Kamineneni 1975) and there are a few minor occurrences of kyanite in the northeastern part of the province (Frith, R. A. et al. 1977, Percival 1979).

Structural Geology

Numerous structural studies of the Slave Province have been performed (Henderson 1943, Ross 1966, Tremblay 1952, 1976, Ramsay 1973, Fyson 1975, 1978, 1981, Drury 1977). The majority of the structure can be related to a major tectonic event at ~2.6 Ga. Fyson (1975), on the basis of field studies in the Gordon Lake-Ross Lake area and a review of earlier mapping over a larger area, determined a three-phase sequence: two major periods of folding (D_1 , D_2) followed by deformation (D_3) related to the intrusion of post-metamorphism plutons.

Greenschist metamorphism prevailed during D_1 and folds resulting from this deformation are isoclinal. Folding during D_2

was also predominantly isoclinal and a prominent north trending schistosity was developed. Evidence for D_3 is mainly the crenulation of this schistosity; during this last period of deformation the metamorphic grade is thought to have been decreasing.

The structural trends in the western half of the province are northerly to northeasterly and these are delineated by the orientation of folds in the metasediments. The folds are similar and normally isoclinal with vertical to steeply dipping axial planes and moderate plunges. Folding is much less apparent in the volcanic sequences (McGlynn and Henderson 1972, Fyson 1975, 1981).

3. GOLD MINERALIZATION IN THE YELLOWKNIFE DISTRICT

Introduction

Gold has been produced from rocks of the Slave Province since the mid-1930's. Production from that time until the present amounts to approximately 11 million ounces which, given the area of the province ($\sim 190,000 \text{ km}^2$), is comparable to that from other Archean cratons (cf. Anhaeusser 1976).

Over 240 gold showings and deposits are known within the Slave Province but the bulk of production has come from only 22 of them. The majority of these occurrences are of the quartz lode, or vein, type and most are within 150 km of Yellowknife (Padgham 1980b).

Description of the Mineralization

It has long been recognized that the gold-quartz mineralization can be divided into two main categories based on the host rock lithology (Henderson and Jolliffe 1939). These are: mineralization hosted by volcanic rocks, and mineralization within sedimentary country rocks.

Gold Mineralization in Metavolcanics

It is from the metavolcanic rocks that the bulk of the gold production has come ($\sim 85\%$). They have been studied in great detail including comprehensive research by Boyle (1955, 1959, 1961, 1979). The gold mineralization occurs in auriferous quartz veins and in north-northeasterly trending quartz-carbonate-sericite shear zones

within the metabasalts of the Yellowknife Greenstone Belt. There are two main shear zones: the Campbell shear of the Con mine and the more complex Giant shear of the Giant Yellowknife mine.

The volcanic rocks are extensively altered having variously undergone chloritization, carbonatization, pyritization and sericitization (Boyle 1961, 1979). The chief metallic minerals, occurring with quartz bodies and silicified zones, are pyrite, arsenopyrite, stibnite, chalcopyrite, sphalerite, galena and a number of sulphosalts and tellurides (Coleman 1953, 1957, Boyle 1961). Theories of genesis of these deposits are reviewed later in this thesis.

Gold Mineralization in Metasediments

The metasediments contain many of the gold showings within the Slave Province, yet these are only responsible for about 4% of the total gold production. The gold occurrences in the metasedimentary rocks have been little studied but their structural control has been noted and Henderson and Jolliffe (1939) classified them into four types which have since been slightly modified (Lord 1951, Boyle 1961, 1979).

These four types are:

1. Quartz veins in contorted schist zones and faults that transect the sedimentary beds.
2. Quartz veins and small stockworks in schist zones and fractures that parallel the sedimentary beds. These comprise quartz veins and stockworks in ruptured and sheared beds and bedding planes, dragged slate beds, contacts and saddle reefs on the noses of folds.

3. Quartz veins and sheeted zones in ruptured and sheared axes of isoclinal folds.

4. Quartz veins and stringer zones in irregular fractures and openings without any continuity or special relationships.

The Ptarmigan and Tom deposits are examples of Type 1. The TA, Joon and Ruth deposits occur in sheared beds and/or bedding planes, as does part of the Camlaren mineralization, and these belong to Type 2. The Camlaren mine also has mineralization concentrated in the nose of a fold, as perhaps does the AM occurrence; these would also be Type 2. The Hidden Lake showing also probably belongs in this type as it appears to occur approximately parallel to bedding. The Tin showing is of uncertain nature. The location of these nine gold-quartz occurrences is shown in Figure 2.

Auriferous veins within the metasediments are typically of limited lateral and vertical extent, generally being narrow and discontinuous and of small potential tonnage. They may be of high grade, from 1-10 oz. of Au per ton, but none of the deposits has produced much gold.

The gold may be spectacular but is always erratic; it is often associated with sulphide minerals, mainly pyrite, sphalerite, galena, chalcopyrite, minor arsenopyrite and pyrrhotite--the association with sphalerite has been noted in particular (Henderson and Jolliffe 1939). Scheelite is recorded from a few of the occurrences, mainly those in the medium grade metamorphic rocks.

Wall rock alteration is very limited and generally on the

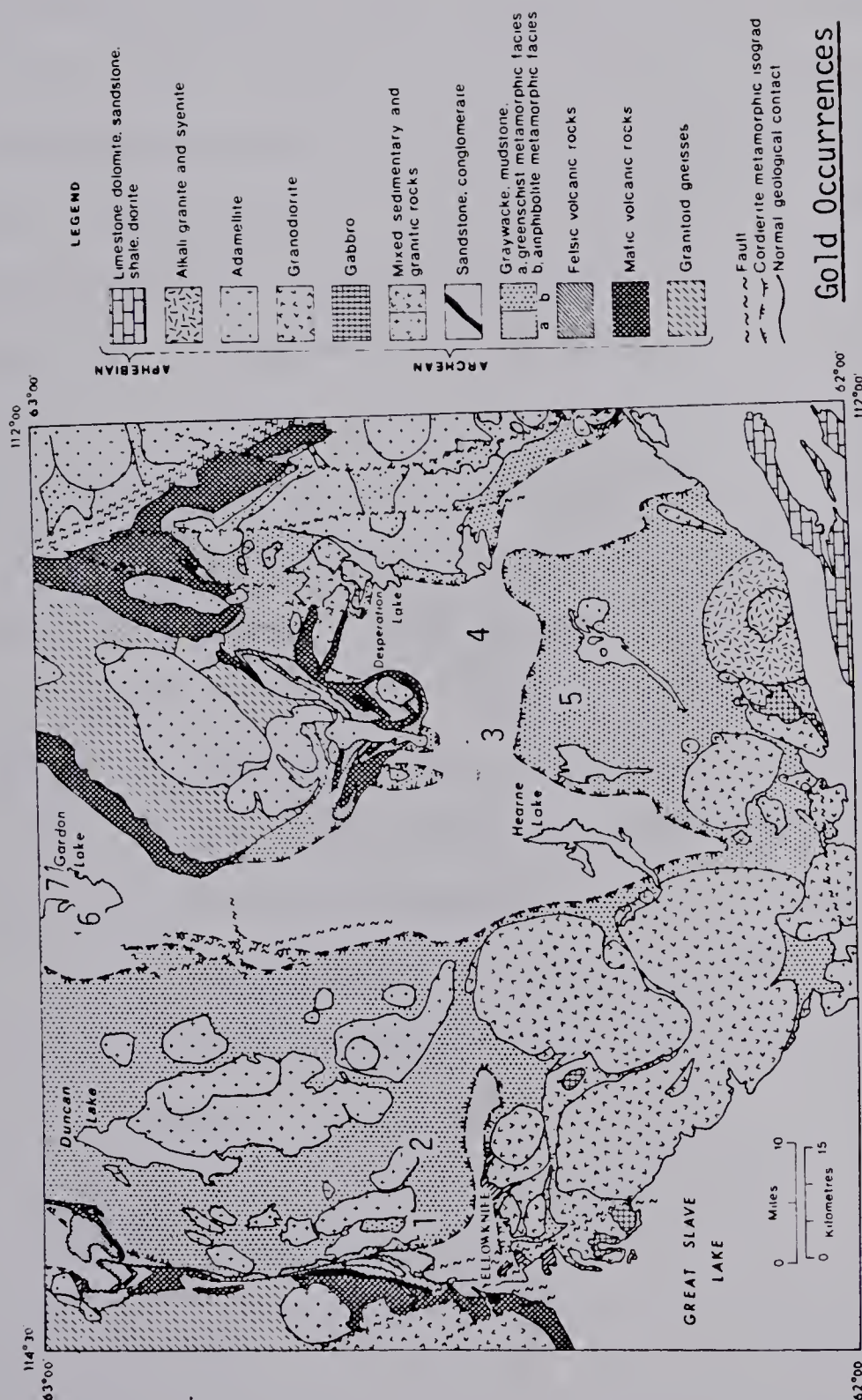


FIGURE 2: Geological sketch map of the Yellowknife-Hearne Lake area, southern Slave Province.

(From Henderson 1977).

The locations of the gold occurrences studied are indicated.

order of a few centimetres. In the low grade metamorphic rocks the alteration zone is often indicated by a thin bleached zone which contains quartz, albite, chlorite, sericite, pyrite, arsenopyrite, occasional pyrrhotite and alteration of biotite. In the medium grade rocks the alteration zone includes quartz, albite-oligoclase, biotite, muscovite, chlorite and some pyrrhotite and arsenopyrite. Tourmaline is common in places, generally associated with biotite (Boyle 1961). In hand specimens sericite (white mica) and pyrite are notable in alteration zones of veins from the low grade rocks while veins from the high grade rocks often have conspicuous biotite, tourmaline and occasional pyrrhotite in their alteration zones.

About as many gold occurrences are known in the low grade strata as in the medium grade rocks, but it is notable that many of these showings occur not far from the cordierite isograd. Occurrences in the high grade metamorphic rocks are not known.

The showings and deposits that have been studied in this work are described in Appendix I, and their locations are given in Figure 2.

4. FLUID INCLUSION STUDIES

4.1 Principles and Previous Work

Introduction

Fluid inclusions are miniscule samples of liquid and/or gas which were trapped in minerals during their crystallization or recrystallization. In the study of mineral deposits their importance lies in the fact that they may represent remnants of the original mineralizing fluids and can provide information on the nature of the fluid and the environment of deposition.

Using fluid inclusions in geochemical and geothermometric studies involves the following major assumptions (from Roedder 1967):

1. The fluid was trapped as a single homogeneous phase when the inclusion was sealed.
2. The cavity in which the fluid is trapped does not change in volume after sealing.
3. Nothing is added to or lost from the inclusion after sealing.
4. The effects of pressure are insignificant, or known.
5. The origin of the inclusion is known.

Various criteria are applied to ensure these assumptions apply to the suite under study while, in general, numerous experimental studies have vindicated them (e.g. Roedder and Skinner 1968, Roedder and Kopp 1975).

Classification of Inclusions

Fluid inclusions are generally classified into three categories: (i) primary, (ii) secondary and (iii) pseudosecondary. Primary inclusions are those that form at the time of crystallization of the mineral; normally by growth irregularities in the crystal. Secondary inclusions form during the healing of fractures after crystallization has occurred. Pseudosecondary inclusions form during the healing of fractures while crystallization is still going on. Obviously data from secondary inclusions, while they may be of value, do not provide information on the nature of the original ore fluid.

Roedder (1967, 1976, 1981) has provided criteria which can be used to distinguish these three classes of inclusion. However most of them could not be used in this present study; the quartz studied is massive and without growth features. Primary inclusions are considered to be those that are isolated, have a random distribution and show no relation to healed fractures or signs of necking. These criteria are not conclusive but are similar to those used successfully in other studies. Secondary inclusions are easier to identify in that they normally occur in planar arrays which represent healed fractures. Given the nature of the quartz no pseudosecondary inclusions can be recognized.

Composition of the Fluid Inclusions

The composition of the inclusions is studied by petrography and by measurement of the depression of freezing temperatures

(more accurately, melting temperatures) of the aqueous solutions in the inclusions. This depression is an indication of the salt content in the fluid. Fortunately sodium chloride is by far the predominant salt in fluid inclusions (Roedder 1972) and so by reference to the NaCl-H₂O phase system the melting temperatures can be related directly to weight percent NaCl (Roedder 1962, Potter et al. 1978). As this is an approximation assuming no other salt ions in the inclusions the determined values are given as weight percent NaCl equivalent (see Clynne and Potter 1977).

Inclusions which have a concentration of NaCl greater than saturation at room temperature will contain halite crystals. The salinity of these inclusions can be determined in 2 ways: either by estimating the volumes of the components and thence calculating the overall weight percent NaCl, or by measuring the temperature of dissolution of the crystal on heating and comparing with the data of Keevil (1942).

If the data obtained are not consistent with the NaCl-H₂O system (figure 3) reference can be made to other systems through these are not as well documented (see Crawford 1981a).

Homogenization of Inclusions

The homogenization temperature of an inclusion is the temperature at which the components within become one phase, i.e. a homogeneous fluid. Sorby in 1858 proposed that the homogenization temperature gives an indication of the temperature of trapping and it is upon this that fluid inclusion geothermometry is based.

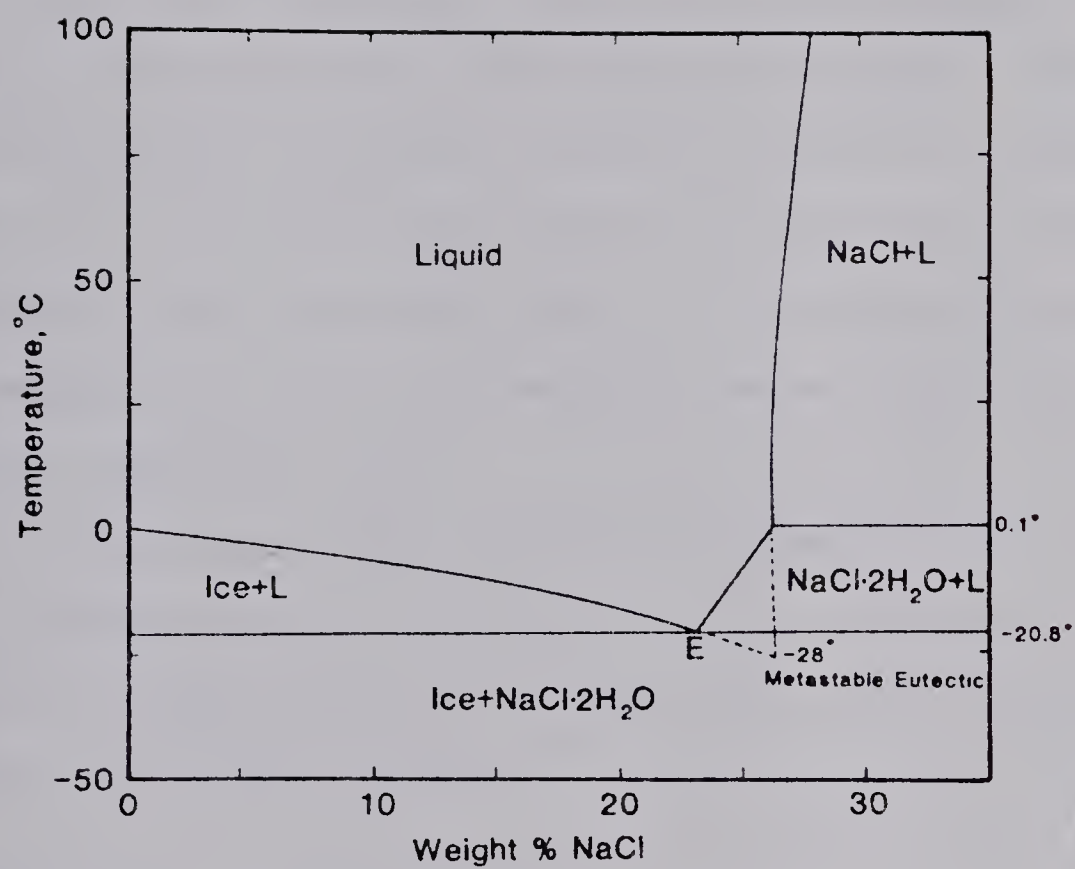


FIGURE 3: The H₂O-NaCl system. (After Potter et al. 1978 and Roedder 1962).

The homogenization temperatures in fact give minimum temperatures of trapping of the original fluids and in most cases it is necessary to calculate a pressure correction before arriving at a temperature of formation. To do this it is necessary to know both the composition of the fluid inclusion, normally in terms of weight percent NaCl equivalent, and the pressure at the time of formation. This latter factor generally has to be determined by independent means. With this information the pressure correction can be determined readily from published graphs (Potter 1977, Lemmlein and Klevtsov 1961).

The pressure is often difficult or impossible to determine and unfortunately the pressure correction (which may amount to hundreds of degrees Celsius) often goes unmentioned in published accounts of inclusion studies.

Previous Studies of Gold Deposits

One of the earliest studies giving inclusion homogenization temperatures is that of Phillips (1868) on gold-quartz veins of California (results of 110-185°C for apparently secondary inclusions) yet relatively few detailed fluid inclusion studies of auriferous quartz veins have been carried out since then. This is no doubt because, as Sawkins et al. (1979) note, they "are notoriously lacking in good material for fluid inclusion studies due to the strong predominance of poorly crystallized quartz containing only very tiny fluid inclusions."

Soviet geologists have performed most of the studies that

do exist and the results are in Russian and often in poorly accessible publications. Some papers are available in translation and more are available as English abstracts (Roedder 1968-1977), but these sources give only a small part of the total information. (About half of all geological literature is in Russian; for fluid inclusion research the proportion is larger, and for inclusion studies on gold-quartz veins still larger, perhaps about 90%.)

For "epithermal" Au-Ag \pm base metals veins (subvolcanic and/or "hot spring" Au-Ag deposits) fluid inclusion studies show homogenization temperatures in the range of 200-330°C, with most falling between 250-300°C. Salinities are normally low to moderate and indications of boiling are common (though not a prerequisite for ore formation). For example in their study of the Sunnyside mine, Colorado, Casadevall and Ohmoto (1977) record homogenization temperatures of 270-315°C and salinities averaging 1 weight percent NaCl equivalent for the gold mineralizing stage. While in a study of auriferous quartz-adularia veins in Nevada Nash (1972) observed temperatures of 200-330°C with the gold-bearing stage at 300°C, and salinities of 1-2 weight percent. He estimated formation temperatures of 285-340°C. At the Pueblo Viejo mine, Dominican Republic, homogenization temperatures of 200°C and above, have been noted along with indications of boiling (S. Kesler, personal communication 1980). In a detailed study of the Baguio vein gold deposits, Phillippines, Sawkins et al. (1979) determined homogenization temperatures of 255-285°C for primary inclusions and 205-245°C

for secondary inclusions. The inclusions are mainly liquid-rich and have salinities of 0-5 weight percent NaCl equivalent; signs of boiling were noted along with small amounts of CH_4 and CO_2 . A similar range of 240-320°C was observed for homogenization temperatures of the main mineralizing stages of Au-Ag vein deposits in Kamchatka (Andrusenko and Shchepot'yev 1974).

In the genetically related disseminated fine-gold deposits of Nevada, Nash (1972) recorded temperatures around 200°C and salinities averaging 6 weight percent.

The data for gold-quartz low sulfide veins are less detailed but certainly more relevant as the veins are more comparable with those of the Yellowknife district. Koltun (1965--Russian original 1957) in a study of auriferous veins in the Urals recorded temperatures of homogenization of 220-420°C with primary inclusions having a wide range in degree of filling. Three phase inclusions containing liquid CO_2 were noted. In a more recent study of one of the deposits (Kochkar') Anufriyev et al. (1974) have confirmed these results observing homogenization temperatures of 230-450°C chiefly from two phase liquid-vapour inclusions, with a few three phase inclusions containing liquid CO_2 . Konovalov (1975) found a similar range of temperatures, 260-460°C, for quartz veins in the Lena gold field. He observed chiefly liquid-rich inclusions which homogenized into the liquid phase; data not being obtainable from most inclusions containing liquid CO_2 . The temperature data could be divided into three groups (260-280°C;

260-300°C and 400-460°C) which corresponded approximately with the metamorphic grade in which the veins occurred (i.e. low, medium and high grade respectively). Analysis of the inclusions showed the presence of CO₂ and CH₄. Salinities with a range of 5-10 weight percent NaCl equivalent are given by Bulynnikov et al. (1977) for deposits of the Central Gold-Ore Field (location?) along with homogenization temperatures which mainly fall in the range of 200-300°C. Rather lower temperatures of 110-265°C have been reported from gold-quartz low sulfide veins of the northeast USSR (Davidenko and Chibikov 1978).

Summarizing this and other Soviet work (Roedder 1968-1977, 1972; Shilo et al. 1971) the following generalizations can be made based on the study of primary inclusions in such veins: the hydrothermal solutions were moderate to high temperature (Th 200-400°C) and consisted of low to moderate salinity NaCl solutions rich in CO₂, (with CO₂ content decreasing towards higher grade ore sections) and with CH₄, though a minor component, ubiquitous.

Western studies on veins of this type are few but the following provide some information. Rye and Rye (1974) in a detailed study of the Homestake mine, South Dakota, observed two main types of inclusion: two phase inclusions consisting of liquid H₂O and a CO₂-rich vapour, and three phase inclusions of liquid H₂O, liquid CO₂ and CO₂-rich vapour. They considered most of these inclusions to be secondary and recorded small amounts of CH₄ in all analyzed samples; no homogenization data are given. In a study of

the conglomerates of the Witwatersrand basin, Shepherd (1977) notes that pebbles of vein quartz with a low proportion of inclusions containing liquid CO_2 are associated with gold, while those which show a relatively high proportion of inclusions with liquid CO_2 are associated with the uranium mineralization. Homogenization temperatures in the range of 200-400°C are given. Krupka et al. (1977) suggested inclusion homogenization temperatures of 210°C-380°C and low to moderate salinities for the mineralizing stage of the O'Brien mine, Quebec, based on observation of two phase inclusions with widely varying degrees of filling (taken as an indication of boiling). For the Dome mine, Ontario, Kerrich and Fryer (1979) recorded homogenization temperatures of 330-370°C for primary inclusions in quartz veins. In the Yellowknife district itself, Chary (1971) observed homogenization temperatures of 270°C (only four measurements) for the Con mine and CH_4 has been detected in quartz from this mine (W. Bale, personal communication 1977). Ramsay (1973) determined temperatures of 150-310°C for primary inclusions and 100-200°C for secondary inclusions in quartz of two veins within the metasediments (the Tom and Ptarmigan occurrences).

As one would expect these results compare quite well with those from the Soviet literature, and this survey shows the predominant role of medium temperature, low to moderate salinity fluids in the formation of auriferous quartz veins.

4.2 Types of Inclusions

As well as being classified into primary, pseudosecondary or secondary, inclusions can be grouped based on their appearance and composition as determined microscopically. Division is essentially on the basis of the components and their phases observed, along with additional information from crushing experiments. The inclusions observed in this study have been categorized into three main types which are described below and illustrated in Figure 4 .

Type I. Liquid-rich. These inclusions are by far the most numerous type observed. They vary from equant to irregular and range in size from <1 to approximately $20\ \mu\text{m}$. Many are in the $5\text{-}10\ \mu\text{m}$ diameter size range but most are $1\ \mu\text{m}$ or less. Various subtypes can be recognized:

- a) Liquid-rich (5-15% vapour by volume) secondary inclusions. Generally simple two-phase inclusions though some contain a small halite daughter mineral (1-5% by volume). Most of the inclusions observed are of this type.
- b) Liquid-rich (10-30% vapour) primary inclusions. Generally two-phase with the vapour often being CO_2 -rich. A three-phase variety is observed in many samples; these contain liquid CO_2 , perhaps up to 20% by volume. The distinction between these two varieties is gradational--an inclusion may contain as much as 10% liquid CO_2 before it can be observed as a separate phase (Roedder 1972). Some of these inclusions contain traces of CH_4 , presumably dissolved

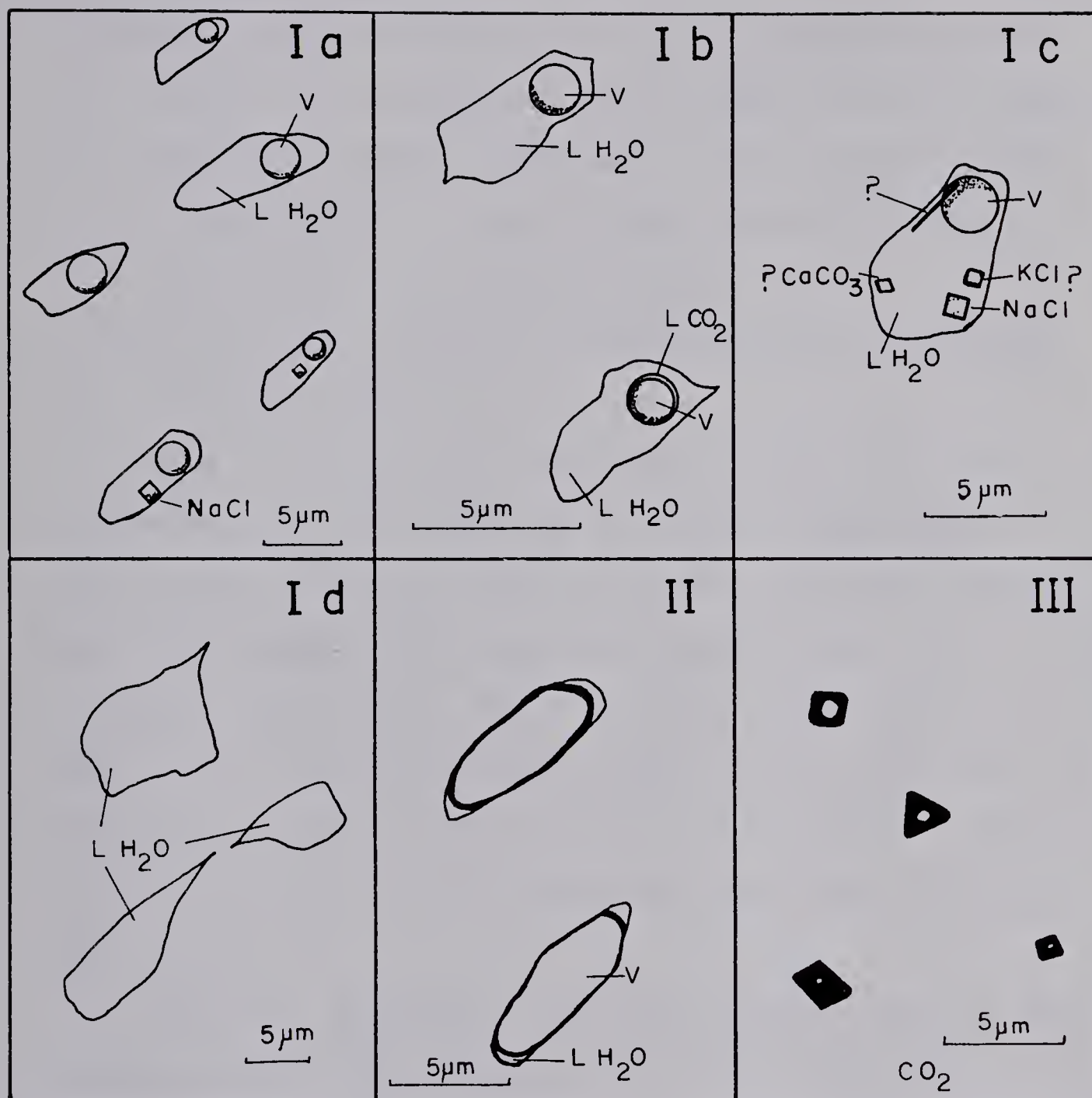


FIGURE 4: Fluid inclusion types observed in quartz of the auriferous veins. See text for explanation.

in the CO_2 phase.

- c) Multiphase inclusions, mainly secondary, though some may be primary. These inclusions, few in number, may contain daughter minerals of halite, another cubic crystal (possibly sylvite), a small anisotropic crystal (possibly calcite) and a thin needle-like crystal (see SEM section).
- d) Liquid-filled inclusions, representing very low temperature late stage secondaries.

Type II. Vapour-rich. These generally equant inclusions are much less common than Type I but were noted in most samples; they are mainly primary but some are secondary. The vapour content varies from virtually 100% ("empty" inclusions) to about 95%. No daughter minerals noted. Vapour is CO_2 -rich with possible traces of CH_4 . (Distinction between liquid-rich and vapour-rich inclusions is of course arbitrary with a division at 50%. However very few inclusions of definite origin were noted in the 30-90% vapour range.)

Type III. CO_2 -bearing. Very small inclusions, many having a negative crystal shape, which could not be seen into. Majority appear to be primary. Crushing shows that some contain CO_2 under high pressure. These may simply be a variety of Type II, or they could grade into the CO_2 -bearing inclusions of Type Ib. Some of these inclusions contain an unidentified noncondensable gas (perhaps nitrogen?).

4.3 Microthermometric Results

The gold-quartz veins provided much material which was unsuitable for fluid inclusion studies but some sixty samples from

nine gold occurrences were usable. The small size of the inclusions made microthermometric measurements difficult and limited the amount of information that could be collected.

Low Temperature Studies

Salinity determinations were carried out on over two hundred inclusions, more than a third of which were classified as primary. These measurements were made by observing the melting temperature of the frozen aqueous phase in the inclusions. All the determinations were on liquid-rich inclusions of Types Ia and Ib.

Hydrohalite, $\text{NaCl} \cdot 2\text{H}_2\text{O}$, which is formed in saturated or near saturated brine at low temperatures, was tentatively identified in a few secondary inclusions which at room temperature contained a halite crystal.

Carbon dioxide hydrate, with an ideal formula of $\text{CO}_2 \cdot 5.75\text{H}_2\text{O}$, would be expected to form in CO_2 -rich inclusions at low temperatures. The melting temperature of this clathrate is dependent on the vapour pressure of CO_2 within the inclusion (and less importantly on the CH_4 content) and commonly ranges between about $+5^\circ\text{C}$ and -5°C , though it can exist up to $+10^\circ\text{C}$ (Kelly and Turneaure 1970, Hollister and Burrus 1976). Given the CO_2 content indicated by crushing studies, this compound was searched for but was not found. It is, however, not easy to identify under the best of conditions, being isotropic and having a refractive index very similar to that for water. The results of the salinity determinations

are tabulated in Appendix III and displayed in Figure 5.

Primary inclusions have a range in salinities from 1 to 18 weight percent NaCl equivalent; most values fall in the range of 3-6 weight percent and the mean value is about 5.5 weight percent. There is no significant difference between the salinities of inclusions from veins within low grade metamorphic rocks and those determined for veins from medium grade rocks.

Secondary inclusions show a range in salinities from 6 to 22 weight percent NaCl equivalent; most values are in the 8-12 weight percent range and the mean is about 11 weight percent with a small subsidiary group of values at 18-19 weight percent. Again determinations from veins in low grade host rocks are comparable with those in medium grade rocks. The average salinity for the secondary inclusions is in fact higher than that given above, for a significant number of secondaries contain halite. From a few measurements of dissolution temperature of these crystals salinities are estimated to be in the 29-31 weight percent range (Keevil 1942). This corresponds well with estimates made using approximate volume calculations.

In summary, the data suggest an original mineralizing fluid of low salinity and a later hydrothermal stage with a fluid of moderate salinity, with the possibility of another late stage fluid which at room temperature varies from over-saturated to just under-saturated. (The age relationship of this high salinity fluid to the moderately saline fluid is unknown.)

The temperature measurements in this salinity study, along

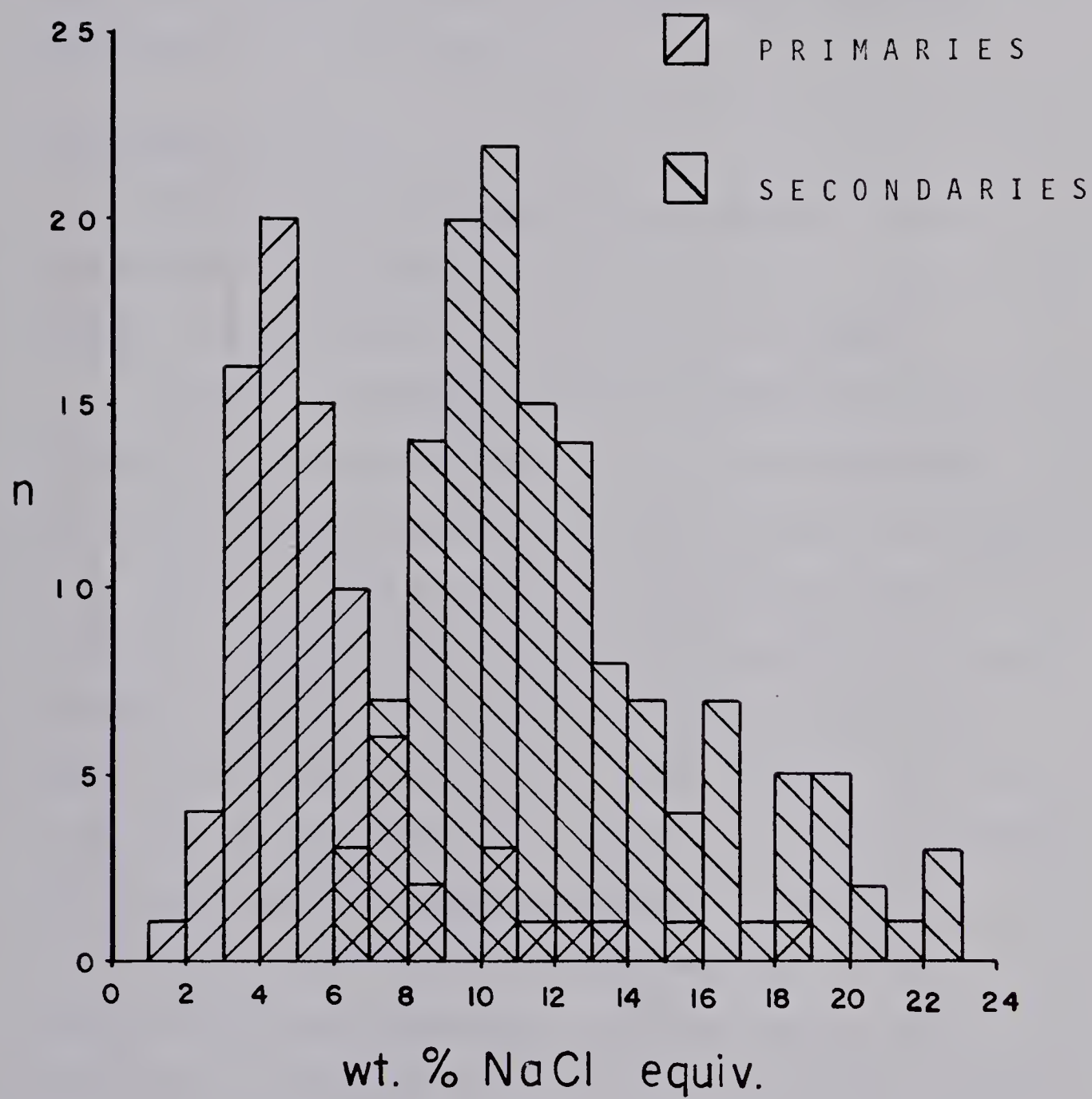


FIGURE 5: Salinity results for primary and secondary inclusions. Determined from Tm ice.

with observation of first melting temperatures between -28°C and -20°C , are consistent with the fluid being a brine containing predominantly sodium and chlorine.

High Temperature Studies

Determinations of homogenization temperatures were performed on nearly five hundred inclusions in the over sixty samples. Over one-third of the inclusions were primary.

Numerous duplicate measurements of homogenization temperatures of particular inclusions were made and these showed good consistency but such measurements were not possible on most of the inclusions. The vapour phase did not always reappear on cooling and some inclusions decrepitated just after homogenization. A number of inclusions of Type Ib and CO_2 -bearing inclusions of Types Ib and III decrepitated before homogenization. This is due to the high internal pressure developed and is a common phenomenon of CO_2 - H_2O inclusions (Roedder and Bodnar 1980, Burruss 1981).

Nearly all of the determinations were made on Type I inclusions and these homogenized in the liquid phase. Only 10 measurements of temperature of homogenization (T_h) were obtained for Type II inclusions; these homogenized in the vapour phase.

The results are tabulated in Appendix IV and shown in Figures 6 and 7.

Primary inclusions have a range in T_h of 200 - 330°C with a mean of 260°C . Figure 7 shows how the data can be divided into two distinct groups based on whether the samples were from veins

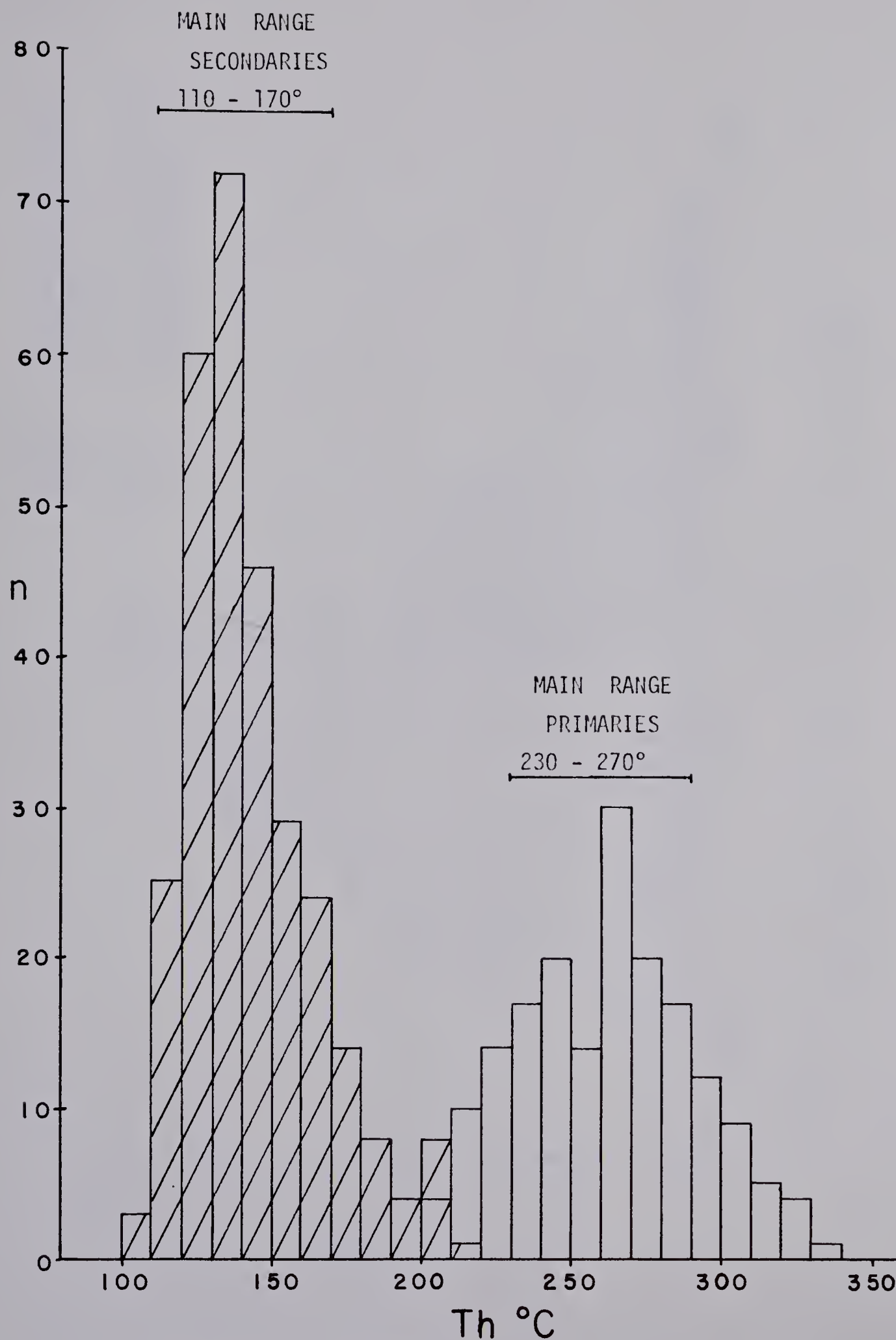


FIGURE 6: Distribution of homogenization temperatures for primary and secondary inclusions.

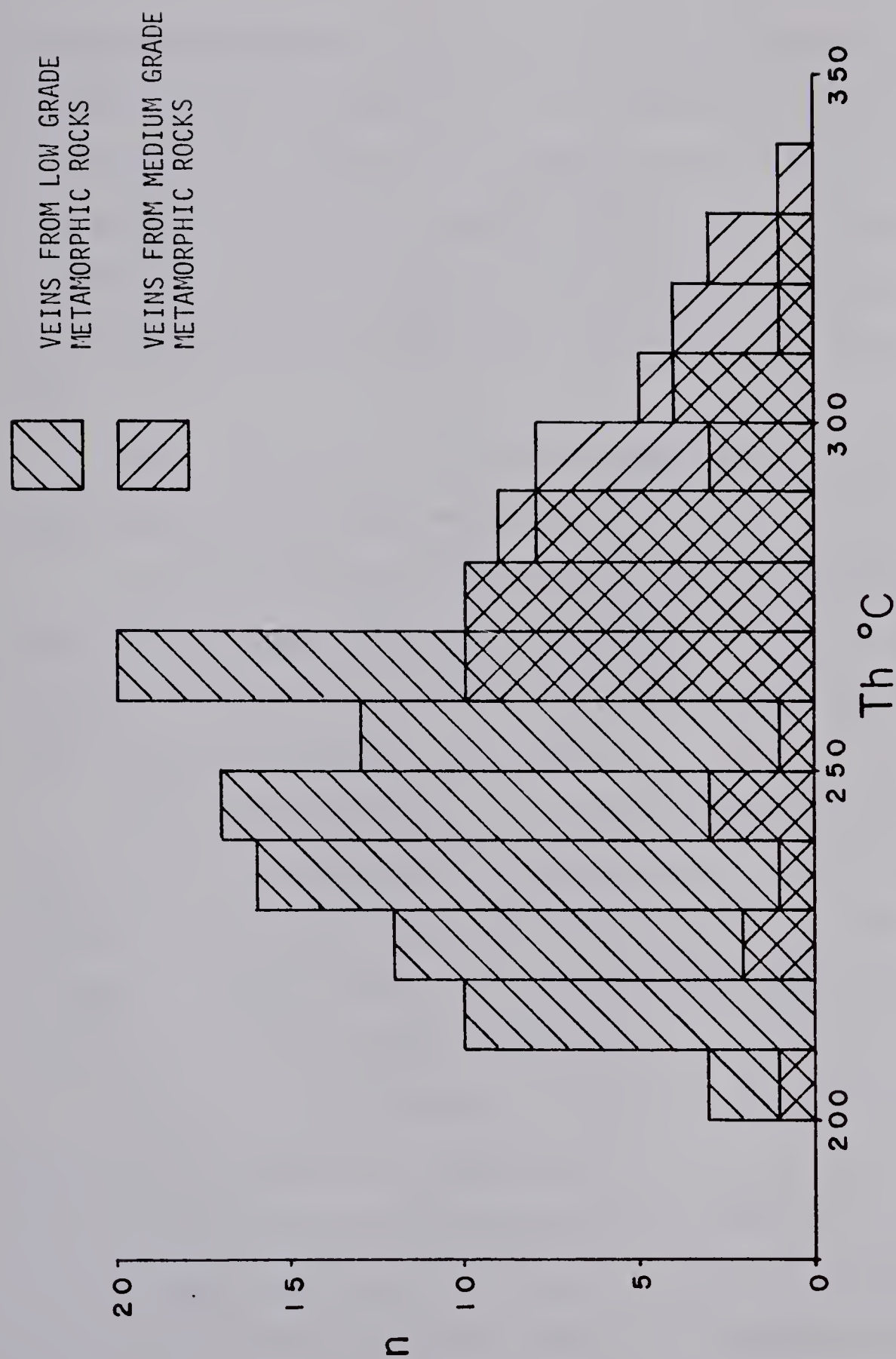


FIGURE 7: Distribution of homogenization temperatures for primary inclusions; veins from low grade and from medium grade metasediments.

in low grade metamorphic rocks or from veins in medium grade rocks. The ranges of the two groups are virtually identical (200-320°C and 200-330°C) but inclusions from quartz of veins hosted by low grade rocks give values with a mean of 250°C and a main range of 210-270°C while values obtained on veins from higher grade rocks have a mean of 280°C and a main range of 260-310°C (cf. Konovalov 1975).

The ten values of Th obtained on vapour phase inclusions ranged from 280-322°C with a mean of 295°C.

Secondary inclusions have a range in Th of 100-220°C with a mean value of about 140°C; most results fall in the range of 120-150°C. There is no difference in Th of inclusions from veins within different metamorphic grade rocks.

The lack of overlap in Th for primary and secondary inclusions could be real although it is possibly due to observer bias whereby inclusions which would have fallen in this range were assigned an uncertain origin (i.e. not definitely primary nor definitely secondary) and went undetermined.

The occurrence of two sets of inclusions (Types I and II primaries), one with liquid predominant and the other vapour-rich and the lack of intergradation between the two suggest "boiling" of the original hydrothermal fluid (more accurately an indication of H₂O-CO₂ immiscibility) (Roedder 1967). The determinations of Th on vapour-dominated inclusions do not contradict this but the small number of values can hardly be considered sufficient to

substantiate this proposition. It cannot be proved that the two types of inclusion are coeval.

However given these reservations, if boiling did take place then no pressure correction is necessary for the primary inclusion data--the homogenization temperatures are equivalent to formation temperatures (Roedder and Bodnar 1980). For the secondary inclusions no estimate of pressure can be made and so the values of T_h represent minimum temperatures for the later stage fluid. As an example of the corrections that might be necessary, pressures of 0.5, 1, and 2 kbar on a 10 weight percent NaCl solution would give corrected values for the 140°C mean value of 190°, 230° and 305°C respectively (Potter 1977).

4.4 SEM Study

To provide further information on the composition of the fluid inclusions quartz samples from six of the gold vein occurrences were studied using a scanning electron microscope (SEM). The aims were to confirm the composition of the brine if possible and to identify any daughter minerals observed. The method used was very similar to that described by Metzger et al. (1977).

A Cambridge S150 SEM fitted with a Kevex energy dispersive analyzer (EDA) was used. Images of the daughter minerals were obtained using the SEM with a scanning electron beam and qualitative analyses were achieved with the beam stationary. An accelerating voltage of 15 kV was used with the electron beam being

~0.25 μm in diameter. Analyses were performed with count rates of 1400-2000 counts per second.

The samples used were fractured fragments of quartz taken, where possible, from specimens which had yielded fluid inclusion samples with multiphase inclusions. Further details of the procedure followed are given in Metzger et al. (1977).

Results

Excellent images of inclusions were obtained (Plates I and II). Most inclusions appeared empty but in a number of cases the inclusions contained or were surrounded by what was apparently a 'decrepitate' (an evaporite from the brine enclosed inclusions, formed on their opening). Using the EDA, all the qualitative analyses determined Na and Cl in the decrepitate, while in a few cases relatively low amounts of K were also detected; no other elements were noted.

As for the daughter minerals no distinct halite cubes were noted; frequently observed in petrographic studies, these crystals were presumably lost on opening of the inclusions. However other daughter minerals were tentatively identified. These were calcite, gypsum, sylvite and a platy K-Al mineral, perhaps a mica or clay mineral. These identifications were based both on the qualitative analyses and the crystal morphology. The analyzer can not detect carbon and neither could sulphur or silicon be determined in the daughter minerals. The samples are coated with gold (so



PLATE I

- a) An inclusion containing NaCl decrepitate on the left and on the right two apparently platy K, Al (Si) minerals. Presumably micas or clays. Ruth.
- b) An irregularly shaped inclusion containing two Ca-rich minerals. The larger one is probably gypsum (cf. Nesbitt and Kelly, 1977, figure 12), the other may be calcite. Camlaren.
- c) A small inclusion, tending towards a negative crystal, with several daughter crystals: a needle-like crystal, Ca-rich perhaps gypsum, and two Cl-rich minerals in the upper left of the inclusion (poorly visible). The larger one contains K and is probably sylvite, the other is unidentified. Note NaCl decrepitate around the inclusion. Joon.
- d) Irregular inclusion containing an arrowhead shaped daughter mineral with a strong Ca spectrum. Crystal is twinned and is probably gypsum. AM.

Note bar scale on all images.

PLATE I



a



b



c



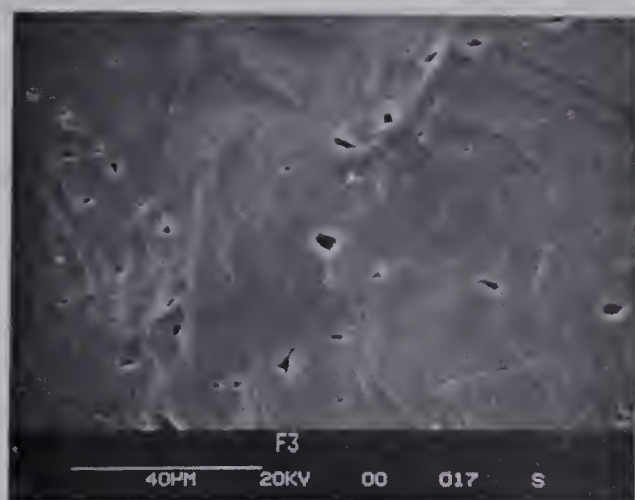
d

PLATE II

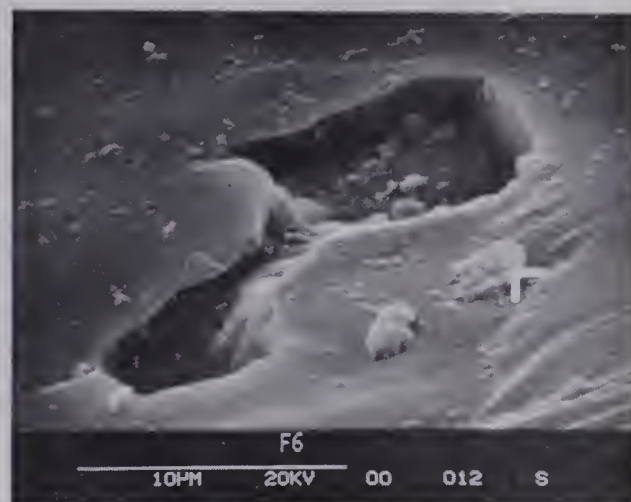
Note bar scale on all images.

- a) Empty inclusions on a fracture surface of quartz. All of the inclusions are secondary as indicated by the linear arrays. Camlaren.
- b) A relatively large inclusion showing signs of necking down. The indicated material, along with most of that in and around the inclusion is NaCl decrepitate. The particle to the lower left of the arrowed NaCl is a fragment of quartz. Hidden Lake.
- c) A very small inclusion, ringed by NaCl decrepitate, showing negative crystal shape. The particle in the left centre is a quartz fragment. Within the inclusion are, in the upper left, a Cl-rich daughter mineral (identity unknown) and in the lower centre, halite--apparently decrepitate rather than a daughter mineral. Hidden Lake.
- d) A filigree of NaCl, a habit which was suprising but not uncommon in the samples observed. It is presumably a decrepitate. Ruth.
- e) A relatively large irregular inclusion containing a Ca-rich rhombohedral daughter mineral, undoubtedly calcite.

PLATE II



a



b



c



d



e

they are electrically conductive) and the X-ray spectrum for gold overlaps and conceals that of sulphur. The X-ray spectrum for silicon from the host quartz swamps what silicon spectrum might be obtained from the daughter minerals.

The mineral dawsonite, $\text{NaAl}(\text{CO}_3)(\text{OH})_2$, reported from gold-quartz veins of California and elsewhere (Coveney and Kelly 1971) was not observed either petrographically or using the SEM.

4.5 Fluid Inclusions and Mineral Exploration

Fluid inclusion research has provided much information on the nature of mineralizing fluids and on the conditions of ore genesis. However in recent years in particular there have been several attempts to make more practical use of fluid inclusions; notably in their application to mineral exploration (Roedder 1977). Nash (1976) clearly shows that the presence of halite-bearing inclusions, especially coexisting with gas-rich inclusions, is a favorable sign in the exploration for porphyry copper deposits. Similarly Kostina and Sushchevskaya (1975) demonstrate how analysis of aqueous extracts from inclusions in quartz of felsic volcanic rocks may provide an indication of massive sulphide ore. Considering that a vast multitude of methods have been applied, or at least attempted, in the prospecting and evaluation of gold deposits (see e.g. Boyle 1979, pp. 446-488) it is not surprising that fluid inclusions have not been ignored in this regard. A brief review of the available information follows.

There have been numerous qualitative observations of the

abundance and nature of fluid inclusions in quartz of vein-type gold mineralization, and comparisons to the barren quartz veins within the same area. Courtis (1890) studied samples from numerous gold mines in California and compared (quartz from barren parts of the vein systems) with 'good quartz' (quartz associated with ore). He noted that gold-bearing quartz had a relative abundance of fluid inclusions many of which contained liquid carbon dioxide. His description of the inclusions as being arranged in 'parallel lines or rows' suggests that they may be of secondary or pseudosecondary origin, yet their association with the gold indicates an apparent connection between CO₂-rich fluids and the deposition (or redeposition) of the gold.

Lindgren (1896, p. 130) in a study of the gold-quartz veins of the Nevada City and Grass Valley districts, California, recorded that fluid inclusions are extremely abundant, noting they are small, irregular in shape and sometimes contain rapidly moving bubbles. Heating to above 30°C indicated the absence of liquid carbon dioxide. He stated there was no recognizable relationship between the fluid inclusions and the richness of the quartz.

Cairnes (1937, p. 53) in a study of gold-quartz veins of the Pioneer-Bralorne area, British Columbia, noted that:

"There was perhaps a suggestion that these inclusions were more abundant and active bubbles more conspicuous in specimens of higher grade gold-quartz but not enough slides were examined to prove or disprove this point."

In a decrepitation study of auriferous quartz veins at the

O'Brien Mine, northwestern Quebec, Blais (1954) found that auriferous quartz decrepitated in the temperature range 75-120°C whereas barren quartz decrepitated above 130°C. A similar study of the Con Mine at Yellowknife by Boyle (1954) determined that the details of any relationship between decrepitation temperatures and gold-bearing quartz are very complex and not consistent, though his results showed there was a tendency for ore quartz to have higher decrepitation temperatures than the barren quartz.

Davidenko and Valpeter (1969) in a study of veins in Western Chukotka, USSR, noted that primary inclusions in gold-bearing veins were multiphase whereas the barren veins were simple gas-liquid inclusions.

Boyer et al. (1967) recorded CO₂-rich inclusions in auriferous quartz from Salsigne, France, and their absence in barren quartz. They noted that such an association is not peculiar to the Salsigne gold mine and gave other examples from gold occurrences in French Guiana, Surinam and Italy, among others. Similarly, Machairas (1970) commented on the association of CO₂-rich inclusions and auriferous quartz. He stated that for gold-bearing quartz, gold content increases as CO₂ content increases, and to substantiate this, presented analyses of samples from auriferous districts in France, French Guiana and Canada.

Vertushkov (1966) determined the "moisture/gas ratio" (essentially the ratio of H₂O to CO₂) in some 150 samples of vein quartz from the southern and central Urals. He shows that the

value of this ratio decreases with metamorphic grade and that the ratio from quartz of gold veins is lower than for quartz of barren veins from the same locality. This study is expanded in Vertushkov et al. (1970) in which the molar ratio $H_2O:CO_2$ in 2500 samples of quartz from various Ural deposits was determined. Vertushkov and coworkers show that this ratio is notably lower for gold-bearing quartz than for barren quartz. For example the following results were obtained from the Byn'gi deposit:

VH_2O/VCO_2	Au content, ppm
8.7	0.6 "barren quartz"
6.0	3.5
2.5	9.2 "ore quartz"

Ryabova (1973) in a study of mineralization in Dagestan, USSR, showed that ore-bearing quartz contains more inclusions per volume of sample than barren quartz. This was indicated by both decrepitation intensity and loss on ignition results. Also the ore-bearing quartz gave decrepitation temperatures of 240-280°C while the barren quartz gave values of 180-210°C.

Korobeynikov and Matsyushevskiy (1973) also noted increased decrepitation approaching and within ore-bearing zones; it being possible to correlate gold concentration and intensity of decrepitation in many auriferous deposits of Siberia and the far eastern USSR.

Summarizing these notes it can be said that, when compared to barren quartz, auriferous quartz may show a greater abundance of

inclusions, a significant but higher content of CO_2 --perhaps best expressed as the ratio of H_2O to CO_2 in the primary inclusions--and generally higher decrepitation temperatures and intensities. Obviously the decrepitation observations are not consistent throughout the various studies and it is likely that the varying nature of the quartz is more significant than the varying gold content.

It is difficult to apply these observations to the veins in the metasediments of the Yellowknife district. Variation in abundance of inclusions is as large within a single vein as it is between auriferous and barren veins. Ramsay (1973) indicates the common occurrence of CO_2 in both the gold-bearing veins and the irregular barren veins. Qualitative observations of Ramsay and of this study have not determined any significant difference in CO_2 content between the two vein types. Also Ramsay finds no significant difference in the homogenization temperatures of inclusions in the auriferous and the barren veins. Results of this research do not alter his observation.

It is apparent that petrographic and microthermometric observations cannot be used to distinguish barren veins from ore-bearing veins in the Yellowknife district, but that there remains the potential to draw a distinction on the basis of an analytical method such as that of Vertushkov (1966).

5. OXYGEN ISOTOPE STUDY

Introduction

Fluid inclusion observations provide an indication of the temperature of formation of the quartz veins and give data on the composition of the hydrothermal fluids responsible for their formation. Preliminary oxygen isotope analyses were performed to augment this information, with the aim of evaluating the use of the method in mineral exploration and, in combination with published data, of determining the ultimate source of the fluids.

Background and Methodology

Water is the main component of hydrothermal fluids and a knowledge of its origin is basic to any hypothesis on the genesis of a mineral deposit. Natural waters of various origins show systematic variations in their ^{18}O contents due to isotopic fractionation during natural chemical and physical processes. Consequently oxygen isotope analysis is an ideal method to characterize ore-forming fluids as it provides information on the nature of the water molecules themselves.

Five major types of water have been distinguished on the basis of isotopic analyses and all may be active in the formation of mineral deposits. The five types are: meteoric water, ocean water, connate water, metamorphic water and primary magmatic water (Taylor 1979). The isotopic character of these waters may be modified and more than one type may be involved in the formation of a

particular deposit (White 1974).

The oxygen isotope ratios of quartz were measured using the BrF_5 method (Clayton and Mayeda 1963). Quartz was treated with BrF_5 for 24 hours at 650°C to liberate oxygen which was reacted with carbon to form carbon dioxide and analyzed on an isotope ratiomass spectrometer. The analyses are reported in the familiar delta value relative to Standard Mean Ocean Water (SMOW) (Craig 1961). Dr. K. Muehlenbachs performed the analyses.

Results and Discussion

The $\delta^{18}\text{O}$ values of the five samples of quartz analyzed are shown in Table I. The values obtained range from 12.3 to 13.4 per mil. Kerrich (1980) has obtained values in the range 10.8-13.6 per mil for vein quartz from several deposits in the Yellowknife area; K. Muehlenbachs has obtained results ranging from 10.8-11.9 per mil for vein quartz from the Con mine (unpublished data). One reason for this preliminary study was to determine if auriferous veins could be distinguished from barren veins on the basis of their oxygen isotope values, as has been suggested possible (Akopyan et al. 1976, Golding and Wilson 1980). To test this proposal two of the samples analysed were taken from barren irregular quartz veins within the same terrain. The results of this study show that no clear distinction can be made between gold-bearing veins and barren veins in the Yellowknife district using this method.

However it is noticeable that the values obtained from the veins within medium grade metamorphic rocks are approximately 1

TABLE 1
OXYGEN ISOTOPE DATA FOR QUARTZ

Sample Location and Number	Metamorphic grade of country rocks	$\delta^{18}\text{O}$ vein quartz
Camlaren 6	Low	13.4
Barren vein 1	Low	13.3
Tom 4	Medium	12.3
Ptarmigan 1	Medium	12.3
Barren vein 2	Medium	12.5

The location of the barren veins is given in Figure 13.

The analytical uncertainty amounts to 0.2 per mil.

permil lighter than those from veins in low grade rocks. This is not surprising if the veins genesis is related to the metamorphism, for it suggests a higher temperature of equilibration in the medium grade metamorphic rocks (Faure 1977). A similar pattern is noted for regional quartz segregation veins in pelitic rocks of the Homestake mine area (South Dakota). Quartz veins in medium grade metamorphic rocks have $\delta^{18}O$ values about 3 permil lighter than those for veins in lower grade rocks (Rye and Rye 1974).

Oxygen isotope data, from the literature, for quartz veins of the Yellowknife district are summarized in Table 2; note that the single value for the Ptarmigan occurrence is similar to that found in this study. Analysis of mineral equilibrium pairs allows isotopic temperatures and values for $\delta^{18}O$ fluid to be calculated and these data of Kerrich and co-workers are included in the table. However, these researchers have used an early value of the oxygen isotope fractionation factor for the quartz-water system (Clayton et al. 1971). Quite different values are obtained using the preferred, revised Clayton et al. (1972) fractionation factor (in Friedman and O'Neil, 1977). Recalculation gives an isotopic temperature of 360°C for Ptarmigan and values of 325-360°C (quartz-muscovite) and 355-390°C (quartz-chlorite) for the Con mine.

The difference between the isotopic temperature for Ptarmigan and the temperatures of homogenization of fluid inclusions in samples from Ptarmigan (this study) is some 50-120°C. This suggests, assuming the samples used in the different studies to be similar, a pressure of ~0.6 to ~1.4 kbar (60-140 MPa) at the time of formation (data for a 5 weight percent NaCl solution, Potter 1977).

TABLE 2

OXYGEN ISOTOPE DATA

(Kerrick and coworkers)

Location	$\delta^{18}\text{O}$ vein quartz	$\delta^{18}\text{O}$ mineral	$\Delta^{18}\text{O}$ quartz-mineral	$T^{\circ}\text{C}^*$	$T^{\circ}\text{C}^{**}$	$\delta^{18}\text{O}^*$ fluid	$\delta^{18}\text{O}^{**}$ fluid
Con mine	11.50 - 12.53	---	3.5 - 3.8 (a)	400 - 450	325 - 360	---	
		5.97-6.58(b)	5.53-5.95(c)	440 - 480	355 - 390	7.9 - 8.2	6.7 - 6.9
Ptarmigan	12.60	6.67 (b)	5.93 (c)	440	360	8.2	7.0

(a) $\Delta^{18}\text{O}$ quartz-muscovite(b) $\delta^{18}\text{O}$ chlorite(c) $\Delta^{18}\text{O}$ quartz-chlorite

Data from: Kerrich (1980), Kerrich et al. (1980)

Hutchinson et al. (1980 and Kerrich and Fryer (1981).

Errors in the calculated isotopic temperatures amount to $\pm 30^{\circ}\text{C}$.

* Isotopic temperatures and $\delta^{18}\text{O}$ fluid values calculated from the equations given by Wenner and Taylor (1971), O'Neil and Taylor (1969) and, supposedly, Clayton et al. (1972). However Kerrich and coworkers have apparently used an earlier equation of Clayton et al. (1971).

**Based on Wenner and Taylor (1971), O'Neil and Taylor (1969) and revised Clayton et al. (1972) In Friedman and O'Neil (1977).

Similarly recalculating the $\delta^{18}\text{O}$ fluid values gives a $\delta^{18}\text{O}$ fluid of 7.0 permil for Ptarmigan and 6.7 to 6.9 permil for the Con mine. Unfortunately these values do not provide conclusive information on the source of the hydrothermal fluids. Primary magmatic waters have a restricted range of $\delta^{18}\text{O}$ (+5.5 to +10.0) whilst metamorphic waters have a wide range (+4 to +25) (Taylor 1979). The values for the veins in the Yellowknife district fall within the overlap between the two types; the data are compatible with either a magmatic fluid or a metamorphic fluid for the formation of the veins.

Conclusions

It is clear from this preliminary study that oxygen isotope analysis alone cannot determine the specific source of the mineralizing fluids. Neither can it be used as a straightforward evaluation tool. Nevertheless a detailed oxygen isotope study of the veins and of the host metasediments could provide a better understanding of the relationship between the two and of the formation of the veins.

6. DISCUSSION AND SUMMARY

Origin of the Gold Mineralization

Various hypotheses have been forwarded for the origin of the gold veins in the Yellowknife district.

Henderson and Jolliffe (1939) proposed that the veins in the sediments were genetically connected with some Precambrian granite and that the veins in the volcanics owed their origin to a deep-seated magmatic source.

Such a magmatic-hydrothermal origin was also supported by Coleman (1957) but in a series of papers culminating in a substantial memoir Boyle (1955, 1959, 1961) proposed a different genesis. He concluded that the veins in the volcanics were derived by lateral secretion into dilatant zones during regional metamorphism. He also applied this model to the auriferous veins in the sedimentary rocks.

Various authors (Ames 1962, McConnell 1964, Chary 1971) challenged Boyles conclusions and--in part through reinterpreting Boyles data--supported a magmatic-hydrothermal origin. However, general disenchantment with classic magmatic-hydrothermal theories, largely due to the recognition of syngenetic features in various ore deposits, along with studies of gold mineralization elsewhere provided increased support for Boyle's proposal of lateral secretion as an important ore-forming mechanism.

The controversy over the origin of the veins has recently

been reopened by the studies of Kerrich and coworkers (Kerrich et al. 1977, Kerrich 1980). They proposed that the shear zones in the volcanics acted as high-permeability conduits along which convective fluid flow was concentrated. The fluids were derived at depth from dehydration reactions in the amphibolite metamorphic zone and deposited gold and silica as they rose and cooled.

This model is in many ways not greatly dissimilar from that of Boyle, for he also considered that the shear zones channelled fluids from depth, but he advocated a significant contribution of ore and other elements from the surrounding country rocks by diffusion processes leading to lateral secretion.

To determine which of these models (if any) is compatible with the collected data and most applicable to the veins of the present study, it is pertinent to briefly review information, derived from experimental studies and descriptions of gold mineralization elsewhere, on the source, transport and deposition of gold, and to discuss these observations with respect to the Yellowknife district.

Source of the Gold

The source of gold in vein deposits has been much considered in the literature, but proposals offered are normally quite speculative for it is unusual that the source can be identified with any certainty.

Viljoen et al. (1970) and Pyke (1975) have suggested a

connection between gold vein deposits and ultramafic rocks on the basis that these rocks have a high primary gold content. Similarly Stephenson and Ehmann (1971) tentatively propose mafic intrusions as a source of gold for Archean mineralization in Manitoba. However more recent work suggests that in most cases ultramafic rocks do not have above average gold contents (Anhaeusser et al. 1975, Kwong and Crocket 1978, Tilling et al. 1973) and the study of Kwong and Crocket indicates that for a greenstone belt in northern Ontario the gold abundance in unaltered volcanic and sedimentary rocks is typically less than 2 ppb.

Boyle (1976)--considering the typical content of gold in unaltered rocks of greenstone belts to range from 5-12 ppb--illustrated how carbonatization or granitization (i.e. ultrametamorphism) can release enormous amounts of gold and suggested that there is no problem in deriving gold; i.e. normal rocks can be the source of gold. Nevertheless it is obvious that if there does happen to be a primary concentration of gold it will increase the likelihood of a secondary concentration occurring (perhaps in the form of gold-quartz veins). In this respect sulphide schists, iron formations, intrusive quartz feldspar porphyries and sulfide-rich carbonaceous shales were offered as the most favourable source rocks (Boyle 1976).

Applying this to the metasediments of the Yellowknife district it is possible the carbonaceous shales acted as source-rocks, though given that the greywackes formed from erosion of felsic

volcanic and intrusive rocks (Henderson 1975) it is unlikely that their initial gold content was particularly low.

Transport and Deposition of the Gold.

Experimental studies of gold transport suggest that gold may be transported either as a chloride complex or as a sulphide complex.

Transport as a chloride complex is favoured in high temperature, acidic, oxidizing solutions (e.g. Helgeson and Garrels 1968, Henley 1973) while sulphide complex transport is more likely in lower temperature, alkaline, less-oxidizing solutions (Weissberg 1970, Rytuba and Dickson 1974). Seward (1973) demonstrated that at temperatures below 350°C maximum gold solubility in approximately neutral pH solutions (considered most comparable with ore-forming fluids) will be achieved with thio complexes.

At high temperatures with gold highly soluble in chloride solutions buffered at an oxygen fugacity generated by the hematite-magnetite pair, deposition of the gold can be brought about by cooling or by changes to lower fugacity (Henley 1973). At lower temperatures with gold existing as thio complexes, deposition of gold can be brought about by decreasing temperature, change in pH or an increase in oxygen fugacity (Rytuba and Dickinson 1974, Seward 1973).

Which of these methods of transport was operable in the Yellowknife district cannot be ascertained from the data collected in this study. The chloride composition of the hydrothermal fluid is indicated by the fluid inclusion data, but the observations of

Ramsay (1973) suggest that the fluid which deposited the barren veins also had a similar composition. It is noticeable that the barren veins do not contain sulphide minerals and this lack of gold and sulphur suggests that sulphur species may have played a predominant role in complexing and transport of the gold.

Considering the high carbon dioxide content of the hydrothermal fluid, another possibility is that of gold transport by carbonate or bicarbonate complexes. Such complexes may be important in the transport of uranium (Langmuir 1978) and have been suggested for the transport of tungsten (Higgins 1980) but the possibility of similar complexes being important in gold transport has apparently received little experimental study.

Factors important in causing the deposition of gold in the Yellowknife district are difficult to discern. From experimental work Henley (1973) and Rytuba and Dickinson (1974) suggest temperature may be important and this would certainly answer why the veins occur mainly near the cordierite isograd. Such a limited spatial distribution has been noted in numerous districts of gold-quartz vein mineralization in metasediments. For example, the gold districts of Lena, USSR (Buryak 1967), New Zealand (Williams 1965) and Nova Scotia (Taylor and Schiller 1966).

Given that the gold-quartz veins at Yellowknife tend to form in dilatant zones--fractured or sheared slate horizons, the noses of folds--decrease in pressure may have been of significance in making gold complexes unstable and bringing about deposition.

However based on experimental studies Seward (1973) considered it of limited importance.

A reduction in oxygen fugacity would also likely cause deposition of gold though its role in the Yellowknife district is difficult to evaluate. However the association of the gold mineralization with blue, dark grey, or black quartz (i.e. quartz containing graphite or amorphous carbon) is notable (Boyle 1953). Such an association has been observed in numerous gold districts (e.g. Thorpe 1975) and in some deposits it has been possible to quantify the relationship between gold and carbon (Mel'nikov 1980, Zakharova 1975). This would suggest reduction of oxygen fugacity is important in gold deposition. Consequently the slate (and carbonaceous biotite schists) may not only have provided an important structural control (acting as a relatively impermeable barrier, or as a dilatant zone due to fracturing, shearing or folding) but also a chemical control on the deposition of the gold.

"Boiling" or fluid immiscibility may also have encouraged the instability of the transport complexes, particularly if carbonate complexes were involved. However "boiling" has been noted in barren veins (e.g. Crawford et al. 1979) and is not always associated with ore deposition in vein deposits (Spooner 1981).

Summary

In summarizing this information and the data from the fluid inclusion study the following model, similar to those of Petrov et al.

(1972) and Henley et al. (1976), can be outlined.

A hydrothermal fluid of high temperature and relatively low salinity, derived from dehydration accompanying amphibolite grade metamorphism of the sediments, migrated upwards through the rock sequence carrying gold dissolved from the country rocks. On decreasing temperature, pressure and oxygen fugacity the gold complexes became unstable depositing gold at moderate temperatures. The temperatures of deposition (in the order of 250-350°C) along with wall rock alteration and structural considerations suggest the mineralization took place after the peak of metamorphism as temperatures were declining and compressional forces were released.

Later stage hydrothermal fluids were of low temperature and moderate to high salinity. These fluids are similar both in Th and salinity to fluids responsible for Mississippi Valley-type mineralization; their age is unknown and they could represent a Proterozoic or Phanerozoic event. The observation of Boyle (1969) that gold is sometimes associated with secondary inclusions suggests that these late stage fluids partially remobilized some of the gold.

Conclusions

The chief conclusions of this work are as follows:

- 1) Fluid inclusions and oxygen isotope data, along with consideration of the appropriate phase systems, indicate that deposition of the quartz veins and associated gold mineralization occurred from a fluid of moderate temperature (250-350°C) and low salinity (~5 weight percent NaCl equivalent) at a minimum pressure of about

1 kbar (100 MPa).

2) A later stage hydrothermal fluid was of low temperature ($\sim 140^{\circ}\text{C}$) and moderate to high salinity (~ 11 -30 weight percent NaCl equivalent) and partially remobilized the gold.

3) The data from this study alone are inconclusive but considered in conjunction with published work, leads the author to favour gold-quartz vein formation through metamorphogenic processes, largely in the way that Fyfe and Henley (1973) and Henley et al. (1976) have outlined.

4) With regard to future studies further extensive fluid inclusion research does not appear warranted considering the poor quality of the sample material and contained inclusions. Nevertheless, a detailed study of a single deposit involving research on fluid inclusions, oxygen isotope and wall rock alteration, along with observation of the distribution of gold and carbon species (notably C, CO_2 and CH_4), could provide significant information on the genesis of such deposits. The reopening of the Camlaren mine could provide an ideal opportunity for such a study.

On a more general aspect, the author, through this study and associated literature reviews, considers that the role of carbon (i.e. C, CO_2 , CH_4 , CO_3^{2-} , HCO_3^-) in the transport and/or deposition of gold deserves further research.

BIBLIOGRAPHY

- AKOPYAN, M.S., ISKANDARYAN, G.G. and DONTSOVA, Ye.I. 1976. An oxygen-isotope study of the Megradzor gold-ore deposit. *Geochemistry International*, 13, (1), pp. 172-176.
- ANDRUSENKO, N.I. and SHCHEPOT'YEV, Yu.M. 1974. Temperatures and stages in the formation of central Kamchatka subvolcanic Au-Ag deposits. *Geochemistry International*, 11, pp. 130-137.
- ANHAEUSSER, C.R. 1976. The nature and distribution of Archean gold mineralization in southern Africa. *Minerals Science and Engineering*, 8, pp. 46-84.
- ANHAEUSSER, C.R., FRITZE, K., FYFE, W.S. and GILL, R.C.O. 1975. Gold in "primitive" Archean volcanics. *Chemical Geology*, 16, pp. 129-135.
- ANUFRIYEV, Yu.N., STUPAKOV, G.P. and MOSKALYUK, A.A. 1974. Characteristics of quartz of Kochkar' gold deposit. *International Geology Review*, 16, pp. 405-416.
- BARAGAR, W.R.A. 1961. The mineral industry of the District of Mackenzie, Northwest Territories, 1960. *Geological Survey of Canada, Paper 61-3*, 29 p.
- _____. 1962. Mineral industry of District of Mackenzie and part of the Keewatin, 1961. *Geological Survey of Canada, Paper 62-1*, 41 p.
- _____. 1966. Geochemistry of the Yellowknife volcanic rocks. *Canadian Journal of Earth Sciences*, 3, pp. 9-30.
- BARAGAR, W.R.A. and HORNBOOK, E.H. 1963. Mineral industry of District of Mackenzie, 1962. *Geological Survey of Canada, Paper 63-9*, 44 p.
- BARAGAR, W.R.A. and McGLYNN, J.C. 1976. Early Archean basement in the Canadian Shield: a review of the evidence. *Geological Survey of Canada, Paper 76-14*, 20 p.
- BLAIS, R.A. 1954. A petrologic and decrepitometric study of the gold mineralization at the O'Brien mine, northwestern Quebec. Ph.D. thesis, University of Toronto, 292 p.

- BOYER, F., TOURAY, J-C. et VOGLER, M. 1967. Présence d'inclusions à CO₂ liquide dans des quartz du district aurifère de Salsigne. Comptes Rendus des séances de l'Académie des Sciences (Paris), Série D, 265, pp. 11-13.
- BOYLE, R.W. 1953. On the colour of black and grey quartz from Yellowknife, Northwest Territories, Canada. American Mineralogist, 38, pp. 528-535.
- _____. 1954. A decrepitation study of quartz from the Campbell and Negus-Rycon shear zone systems, Yellowknife, Northwest Territories. Geological Survey of Canada, Bulletin 30, 20 p.
- _____. 1955. The geochemistry and origin of the gold-bearing quartz veins and lenses of the Yellowknife greenstone belt. Economic Geology, 50, pp. 51-66.
- _____. 1959. The geochemistry, origin and role of carbon dioxide, water, sulphur and boron in the Yellowknife gold deposits, N.W.T., Canada. Economic Geology, 54, pp. 1506-1524.
- _____. 1961. The geology, geochemistry, and origin of the gold deposits of the Yellowknife district. Geological Survey of Canada, Memoir 310, 193 p.
- _____. 1969. Hydrothermal transport and deposition of gold. Economic Geology, 64, pp. 112-115.
- _____. 1976. Mineralization processes in Archean greenstone and sedimentary belts. Geological Survey of Canada, Paper 75-15, 45 p.
- _____. 1978. Iron reduction around gold-quartz veins, Yellowknife district, Northwest Territories, Canada--a discussion. Economic Geology, 73, pp. 110-112.
- _____. 1979. The geochemistry of gold and its deposits (together with a chapter on geochemical prospecting for the element). Geological Survey of Canada, Bulletin 280, 584 p.
- BOYLE, R.W., ALEXANDER, W.M. and ASLIN, G.E.M. 1975. Some observations on the solubility of gold. Geological Survey of Canada, Paper 75-24, 6 p.

- BULYNNIKOV, V.A., DENISENKO, N.P. and ANDREEVA, T.A. 1977. On temperature of formation of quartz veins of the Central Gold-Ore Field. (Abstract) Fluid Inclusion Research-Proceedings of COFFI, 10, pp. 36-37.
- BURRUS, R.C. 1981. Analysis of phase equilibria in C-O-H-S fluid inclusions. In Short course in fluid inclusions: applications to petrology. Edited by L.S. Hollister and M.L. Crawford. Mineralogical Association of Canada, pp. 39-74.
- BURYAK, V.A. 1967. Gold ore formations of the Lena gold-bearing region. International Geology Review, 9, pp. 1553-1559.
- CAIRNES, C.E. 1937. Geology and mineral deposits of Bridge River mining camp, British Columbia. Geological Survey of Canada, Memoir 213, 140 p.
- CASADEVALL, T. and OHMOTO, H. 1977. Sunnyside mine, Eureka mining district, San Juan County, Colorado: geochemistry of gold and base metal ore deposition in a volcanic environment. Economic Geology, 72, pp. 1285-1320.
- CHARY, K.N. 1971. An isotopic and geochemical study of gold-quartz veins in the Con-Rycon mine, Yellowknife, (NWT). M.Sc. thesis. University of Alberta. 90 p.
- CLAYTON, R.N. and MAYEDA, T. 1963. The use of bromine penta-fluoride in the extraction of oxygen from oxides and silicates. Geochimica et Cosmochimica Acta, 27, pp. 43-52.
- CLAYTON, R.N., O'NEIL, J.R. and MAYEDA, T.K. 1971. (Personal communication in Wenner and Taylor 1971).
- CLAYTON, R.N., O'NEIL, J.R. and MAYEDA, T.K. 1972. Oxygen isotope exchange between quartz and water. Journal of Geophysical Research, 77, pp. 3057-3067.
- CLYNNE, M.A. and POTTER, R.W. 1977. Freezing point depression of synthetic brines. Geological Society of America, Abstracts with Programs, 9, p. 930.
- COLEMAN, L.C. 1953. Mineralogy of the Yellowknife Bay area, N.W.T. American Mineralogist, 38, pp. 506-527.
- _____. 1957. Mineralogy of the Giant Yellowknife Gold mine, Yellowknife, N.W.T. Economic Geology, 52, pp. 400-425.

- COLLINS, P.L.F. 1979. Gas hydrates in CO₂-bearing fluid inclusions and the use of freezing data for estimation of salinity. *Economic Geology*, 74, pp. 1435-1444.
- COURTIS, W.M. 1890. Gold quartz. *American Institute of Mining and Metallurgical Engineers, Transactions*, 18, pp. 639-644.
- COVENEY, R.M. and KELLY, W.C. 1971. Dawsonite as a daughter mineral in hydrothermal fluid inclusions. *Contributions to Mineralogy and Petrology*, 32, pp. 334-342.
- CRAIG, H. 1961. Standard for reporting concentrations of deuterium and oxygen-18 in natural waters. *Science*, 133, pp. 1833-1834.
- CRAWFORD, M.L. 1981a. Phase equilibria in aqueous fluid inclusions. In *Short course in fluid inclusions: applications to petrology*. Edited by L.S. Hollister and M.L. Crawford. *Mineralogical Association of Canada*, pp. 75-100.
- _____. 1981b. Fluid inclusions in metamorphic rocks--low and medium grade. In *Short course in fluid inclusions: applications to petrology*. Edited by L.S. Hollister and M.L. Crawford. *Mineralogical Association of Canada*, pp. 157-181.
- CRAWFORD, M.L., FILER, J. and WOOD, C. 1979. Saline fluid inclusions associated with retrograde metamorphism. *Bulletin de Minéralogie*, 102, pp. 452-568.
- CUMMING, G.L. and TSONG, F. 1975. Variations in the isotopic composition of volatilized lead and the age of the western granodiorite, Yellowknife, Northwest Territories. *Canadian Journal of Earth Sciences*, 12, pp. 558-573.
- CUNNINGHAM, C.G. and CAROLLO, C. 1980. Modification of a fluid-inclusion heating/freezing stage. *Economic Geology*, 75, pp. 335-337.
- DAVIDENKO, N.M. and CHIBISOV, N.P. 1978. Vertical zonation of a gold-ore deposit in the northeast USSR. *Geochemistry International*, 15 (5), pp. 51-58.
- DAVIDENKO, N.M. and VALPETER, A.P. 1969. Microinclusions in minerals of gold-bearing and barren veins in Western Chukotka. (Abstract) *Fluid Inclusion Research-Proceedings of COFFI*, 2, p. 36.
- DAVIDSON, A. 1972. Granite studies in the Slave Province. *Geological Survey of Canada, Paper 72-1A*, pp. 109-115.

- DEICHA, G. 1950. Essais par écrasement de fragments minéraux pour la mise en évidence d'inclusions de gas sous pression. Société française de minéralogie et de cristallographie, Bulletin, 73, pp. 439-445.
- DRURY, S.A. 1977. Structures induced by granite diapirs in the Archean greenstone belt at Yellowknife, Canada: Implications for Archean geotectonics. Journal of Geology, 85, pp. 345-358.
- FAURE, G. 1977. Principles of isotope geology. J. Wiley and Sons, New York. 464 p.
- FOLINSBEE, R.E., BAADSGAARD, H., CUMMING, G.L. and GREEN, D.C. 1968. A very ancient island arc. American Geophysical Union, Monograph 12, pp. 441-448.
- FOSTER, R.P. 1977. Solubility of scheelite in hydrothermal chloride solutions. Chemical Geology, 20, pp. 27-43.
- FRIEDMAN, I. and O'NEIL, JR. 1977. Compilation of stable isotope fractionation factors of geochemical interest. U.S. Geological Survey, Professional Paper, 440-KK, 12p.
- FRIPP, R.E.P. 1976. Gold metallogeny in the Archean of Rhodesia. In The early history of the Earth. Edited by B.F. Windley, J. Wiley and Sons, London, p. 455-466.
- FRITH, R., FRITH, R.A. and DOIG, R. 1977. The geochronology of the granitic rocks along the Bear-Slave Structural Province boundary, northwest Canadian Shield. Canadian Journal of Earth Sciences, 14, pp. 1356-1373.
- FRITH, R.A., FYSON, W.K. and HILL, J.D. 1977. The geology of the Hackett-Back River greenstone belt--second preliminary report. Geological Survey of Canada, Paper 77-1A, pp. 415-423.
- FYFE, W.S. and HENLEY, R.W. 1973. Some thoughts on chemical transport processes, with particular reference to gold. Minerals Science and Engineering, 5, pp. 295-303.
- FYSON, W.K. 1975. Fabrics and deformation of Archean metasedimentary rocks, Ross Lake-Gordon Lake area, Slave Province, Northwest Territories. Canadian Journal of Earth Sciences, 12, pp. 765-776.

- _____. 1978. Structures induced by granite diapirs in the Archean greenstone belt at Yellowknife, Canada: implications for Archean geotectonics: a discussion. *Journal of Geology*, 86, pp. 767-769.
- _____. 1981. Divergent fold overturning and regional tectonics, southern Slave Province, Northwest Territories. *Precambrian Research*, 14, pp. 107-118.
- GIBBINS, W.A., SEATON, J.B., LAPORTE, P.J., MURPHY, J.D., HURDLE, E.J. and PADGHAM, W.A. 1977. Mineral industry report, 1974, Northwest Territories. Department of Indian Affairs and Northern Development, EGS 1977-5, 267 p.
- GOLDING, S.D. and WILSON, A.F. 1980. The application of oxygen isotope studies to the occurrence of gold mineralization in eastern Australia. (In press).
- GREEN, D.C. and BAADSGAARD, H. 1971. Temporal evolution and petrogenesis of an Archean crustal segment at Yellowknife, N.W.T., Canada. *Journal of Petrology*, 12, pp. 177-217.
- GREEN, D.C., BAADSGAARD, H. and CUMMING, G.L. 1968. Geochronology of the Yellowknife area, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, 5, pp. 725-735.
- HAAS, J.L., JR. 1971. The effect of salinity on the maximum thermal gradient of a hydrothermal system at hydrostatic pressure. *Economic Geology*, 66, pp. 940-946.
- HELGESON, H.C. and GARRELS, R.M. 1968. Hydrothermal transport and deposition of gold. *Economic Geology*, 63, pp. 622-635.
- HENDERSON, J.B. 1970. Stratigraphy of the Yellowknife Supergroup, Yellowknife Bay-Prosperous Lake area, District of Mackenzie. Geological Survey of Canada, Paper 70-26, 12 p.
- _____. 1972. Sedimentology of Archean turbidites at Yellowknife, Northwest Territories. *Canadian Journal of Earth Sciences*, 9, pp. 882-902.
- _____. 1975. Sedimentology of the Archean Yellowknife Supergroup, at Yellowknife, District of Mackenzie. Geological Survey of Canada, Bulletin 246, 62 p.

- _____. 1976. Geology of Hearne Lake and Yellowknife map-areas. Geological Survey of Canada, Open File 353.
- _____. 1977. Archean geology and evidence of ancient life in the Slave Structural Province, Canada. In Chemical evolution of the early Precambrian. Edited by C. Ponnampuruma. Academic Press. New York, pp. 41-54.
- _____. 1978. Age and origin of the gold-bearing shear zones at Yellowknife, Northwest Territories. Geological Survey of Canada, Paper 78-1A, pp. 259-262.
- HENDERSON, J.F. 1939. Beaulieu River area, N.W.T. (preliminary report). Geological Survey of Canada, Paper 39-1, 16 p.
- _____. 1941a. Beaulieu River, District of Mackenzie, N.W.T. Geological Survey of Canada, Map 581A.
- _____. 1941b. Gordon Lake area, Northwest Territories. Geological Survey of Canada, Map 644A.
- _____. 1941c. Gordon Lake south area, Northwest Territories. Geological Survey of Canada, Map 645A.
- _____. 1943. Structure and metamorphism of early Precambrian rocks between Gordon and Great Slave Lakes, Northwest Territories. American Journal of Science, 241, pp. 430-446.
- HENDERSON, J.F. and BROWN, I.C. 1966. Geology and structure of the Yellowknife greenstone belt, District of Mackenzie. Geological Survey of Canada, Bulletin 141, 87 p.
- HENDERSON, J.F. and JOLLIFFE, A.W. 1939. Relation of gold deposits to structure, Yellowknife and Gordon Lake areas, Northwest Territories. Canadian Institute of Mining and Metallurgy, Transactions, 42, pp. 314-336.
- HENDERSON, J.F. and FRASER, N.H.C. 1948. Camlaren mine. In Structural geology of Canadian ore deposits. Canadian Institute of Mining and Metallurgy, Montreal, pp. 269-272.
- HENLEY, R.W. 1973. Solubility of gold in hydrothermal chloride solutions. Chemical Geology, 11, pp. 73-87.

- HENLEY, R.W., NORRIS, R.J. and PATERSON, C.J. 1976. Multistage ore genesis in the New Zealand geosyncline: a history of post-metamorphic lode emplacement. *Mineralium Deposita*, 11, pp. 180-196.
- HIGGINS, N.C. 1980. Fluid inclusion evidence for the transport of tungsten by carbonate complexes in hydrothermal solutions. *Canadian Journal of Earth Sciences*, 17, pp. 823-830.
- HOLLISTER, L.S. and BURRUSS, R.C. 1976. Phase equilibria in fluid inclusions from the Khtada Lake metamorphic complex. *Geochimica et Cosmochimica Acta*, 40, pp. 163-175.
- HOLLISTER, L.S., CRAWFORD, M.L., ROEDDER, E., BURRUS, R.C., SPOONER, E.T.C. and TOURET, J. 1981. Practical aspects of microthermometry. In *Short course in fluid inclusions: applications to petrology*. Edited by L.S. Hollister and M.L. Crawford. Mineralogical Association of Canada, pp. 278-304.
- HUTCHINSON, R.W., FYFE, W.S. and KERRICH, R. 1980. Deep fluid penetration and ore deposition. *Minerals Science and Engineering*, 12, pp. 107-120.
- JEHL, V. 1975. Le métamorphisme et les fluides associés des roches océaniques de l'Atlantique Nord. Thèse de docteur-ingénieur, Université Nancy I. (Annex III reprinted, in part, in the Chaixmeca handbook.)
- JOLLIFFE, A.W. 1942. Yellowknife Bay, District of Mackenzie, N.W.T. Geological Survey of Canada, Map 709A.
- _____. 1946. Prosperous Lake, District of Mackenzie, N.W.T. Geological Survey of Canada, Map 868A.
- KAMILLI, R.J. and OHMOTO, H. 1977. Paragenesis, zoning, fluid inclusion and isotopic studies of the Finlandia vein, Colqui district, central Peru. *Economic Geology*, 72, pp. 950-982.
- KAMINENI, D.C. 1973. Petrology and geochemistry of some Archean metamorphic rocks near Yellowknife, District of Mackenzie. Ph.D. thesis, University of Ottawa, 223 p.
- _____. 1975. Chemical mineralogy of some cordierite-bearing rocks near Yellowknife, Northwest Territories, Canada. *Contributions to Mineralogy and Petrology*, 53, pp. 293-310.

- _____. 1979. Metasedimentary cordierite-gedrite rocks of Archean age near Yellowknife, Canada. *Precambrian Research*, 9, pp. 289-301.
- KAMINENI, D.C. and DIVI, S.R. 1977. Growth of cordierite in the Archean metasediments near Yellowknife, District of Mackenzie, Canada. *Geologische Rundschau*, 66, pp. 255-263.
- KAMINENI, D.C., DIVI, S.R. and TELLA, S. 1979. Time relations of metamorphism and deformation in Archean metasedimentary rocks near Yellowknife, Canada. *Neues Jahrbuch für Mineralogie, Monatshefte*, 1979, pp. 34-38.
- KEEVIL, N.B. 1942. Vapor pressures of aqueous solutions at high temperatures. *Journal of the American Chemical Society*, 64, pp. 841-850.
- KERRICH, R. 1980. Archean gold bearing chemical sediments and veins: a synthesis of stable isotope and geochemical relations. Ontario Geological Survey, Open File Report 5293, pp. 137-211.
- KERRICH, R. and FRYER, B.J. 1979. Archean precious-metal hydrothermal systems, Dome mine, Abitibi greenstone belt, II. REE and oxygen isotope relations. *Canadian Journal of Earth Sciences*, 16, pp. 440-458.
- KERRICH, R. and FRYER, B.J. 1981. The separation of rare elements from abundant base metals in Archean Lode gold deposits: implications of low water/rock source regions. *Economic Geology*, 76, pp. 160-166.
- KERRICH, R., FYFE, W.S. and ALLISON, I. 1977. Iron reduction around gold-quartz veins, Yellowknife district, Northwest Territories, Canada. *Economic Geology*, 72, pp. 657-663.
- KERRICH, R., ROBINSON, D.J., HUTCHINSON, R.W. and HODDER, R.W. 1980. Field relations and geochemistry of Au, Ni, and Cr deposits in ultramafic-mafic volcanic rocks. Ontario Geological Survey, Miscellaneous Paper 93, pp. 144-162.
- KELLY, W.C. and TURNEAURE, F.S. 1970. Mineralogy, paragenesis and geothermometry of the tin and tungsten deposits of the Eastern Andes, Bolivia. *Economic Geology*, 65, pp. 609-680.
- KOLTUN, L.I. 1965. Application of mineralothermometric analysis in studies of the origins of certain gold deposits in Ural. In *Research on the nature of mineral forming solutions*. Edited by N.P. Yermakov. Pergamon Press, New York, pp. 426-457.

- KONOVALOV, I.V. 1975. Temperature of formation of gold-ore deposits in the Lena field as a function of metamorphic facies. Akademiia Nauk SSSR, Doklady, Earth Science Section, 220, pp. 191-193.
- KOROBAYNIKOV, A.F. and MATSYUSHEVSKIY, A.V. 1973. Application of methods of mineral thermometry for prospecting and evaluation of ore necks in endogenic gold deposits. (Abstract) Fluid Inclusion Research--Proceedings of COFFI, 6, pp. 81-82.
- KOSTINA, R.I. and SUSHCHEVSKAYA, T.M. 1975. Inclusions in quartz of felsic volcanic rocks as indicators of the presence of ores. Geochemistry International, 12, (2) pp. 59-63.
- KWONG, Y.T.J. and CROCKET, J.H. 1978. Background and anomalous gold in rocks of an Archean greenstone assemblage, Kakagi Lake area, northwestern Ontario. Economic Geology, 73, pp. 50-63.
- LAMBERT, M.B. 1977. Anatomy of a greenstone belt--Slave Province, N.W.T. Geological Association of Canada, Special Paper 16, pp. 331-340.
- LANGMUIR, D. 1978. Uranium solution-mineral equilibria at low temperatures with applications to sedimentary ore deposits. Geochimica et Cosmochimica Acta, 42, pp. 547-569.
- LEMMLEIN, G.G. and KLEVTSOV, P.V. 1961. Relations among the principal thermodynamic parameters in a part of the system $H_2O-NaCl$. Geochemistry, 1961 (2), pp. 148-158.
- LETNIKOV, F.A., FIBOR, N.V., GANTIMUROVA, T.P., KONOVALOV, I.V., SHKANDRIY, B.O. and SHKARUPA, F.A. 1975. Transport forms of gold and fluid evolution in the production of gold-bearing metamorphogenic quartz veins. Geochemistry International, 12, pp. 126-134.
- LI, L.V. and SHOKHINA, O.I. 1974. Behavior of gold in progressive regional metamorphism of Precambrian rocks of the Yenisey Range. Geochemistry International, 11, pp. 314-321.
- MEL'NIKOV, B.D. 1980. Role of C_{org} in country rocks in localizing ore shoots in a low-sulfide gold-quartz vein. International Geology Review, 22, pp. 1434-1436.
- METZGER, F.W., KELLY, W.C., NESBITT, B.E. and ESSENE, E.J. 1977. Scanning electron microscopy of daughter minerals in fluid inclusions. Economic Geology, 72, pp. 141-152.

- NASH, J.T. 1972. Fluid inclusion studies of some gold deposits in Nevada. U.S. Geological Survey, Professional Paper, 800-C, pp. C15-C19.
- _____. 1976. Fluid inclusion petrology--data from porphyry copper deposits and applications to exploration. U.S. Geological Survey, Professional Paper 907D, 16 p.
- NESBITT, B.E. and KELLY, W.C. 1977. Magmatic and hydrothermal inclusions in carbonatite of the Magnet Cove Complex, Arkansas. Contributions to Mineralogy and Petrology, 63, pp. 271-294.
- NIKIC, Z., BAADSGAARD, H., FOLINSBEE, R.E., KRUPICKA, J., PAYNE LEECH, A. and SASAKI, A. 1980. Boulders from the basement, the trace of an ancient crust? Geological Society of America, Special Paper 182, pp. 169-175.
- O'NEIL, J.R. and TAYLOR, H.P., JR. 1969. Oxygen isotope equilibrium between muscovite and water. Journal of Geophysical Research, 74, pp. 6012-6022.
- PADGHAM, W.A. 1980a. An Archean ignimbrite at Yellowknife and its relationship to the Kam Formation basalts. Precambrian Research, 12, pp. 99-113.
- _____. 1980b. 'U' leads peak exploration pace in NWT. Northern Miner, 65, (52), pp. C6-C7.
- _____. 1980c. Gold workshop, Yellowknife. Geoscience Canada, 7, 80-82.
- PADGHAM, W.A., KENNEDY, M.W., JEFFERSON, C.W., HUGHES, D.R. and MURPHY, J.D. 1975. Mineral industry report, 1971 and 1972. Volume 3 of 3. Northwest Territories west of 104° West longitude. Department of Indian Affairs and Northern Development, EGS 1975-8, 220 p.
- PADGHAM, W.A., SEATON, J.B., LAPORTE, P.J. and MURPHY, J.D. 1976. Mineral industry report, 1973, Northwest Territories. Department of Indian Affairs and Northern Development, EGS 1976-9, 221 p.
- PERCIVAL, J.A. 1979. Kyanite-bearing rocks from the Hackett River area, N.W.T.: Implications for Archean geothermal gradients. Contributions to Mineralogy and Petrology, 69, pp. 117-184.

- PETROV, B.V., KRENDELEV, F.P., BOBROV, V.A. and TSIMBALIST, V.G. 1972. Behavior of radioelements and gold during metamorphism of sedimentary rocks in the Patom Uplands. *Geochemistry International*, 9, pp. 647-655.
- PETROV, B.V., RAZVOZZHAYEVA, E.A. and MAKRYGINA, V.A. 1972. The behavior of volatile components during regional metamorphism of upper Proterozoic rocks of the Patomsk Uplands. *Geochemistry International*, 9, pp. 234-240.
- PHILLIPS, J.A. 1868. Notes on the chemical geology of the gold-fields of California. *Philosophical Magazine, Series 4*, 36 (2), pp. 321-336.
- POTTER, R.W., II. 1977. Pressure corrections for fluid-inclusion homogenization temperatures based on the volumetric properties of the system NaCl-H₂O. *Journal of Research of the U.S. Geological Survey*, 5, pp. 603-607.
- POTTER, R.W., II, CLYNNE, M.A. and BROWN, D.L. 1978. Freezing point depression of aqueous sodium chloride solutions. *Economic Geology*, 73, pp. 284-285.
- POTY, B.P., LERAY, J. et JACHIMOWICZ, L. 1976. Un nouvel appareil pour la mesure des températures sous le microscope: l'installation de microthermométrie Chaixmeca. *Société française de minéralogie et de cristallographie, Bulletin*, 99, pp. 182-186.
- PYKE, D.R. 1975. On the relationship of gold mineralization and ultramafic volcanic rocks in the Timmins area. Ontario Division of Mines, Miscellaneous Paper 62, 23 p.
- RAMSAY, C.R. 1973a. Metamorphism and gold mineralization of Archean metasediments near Yellowknife, N.W.T., Canada. Ph.D. thesis, University of Alberta, 285 p.
- _____. 1973b. Controls of biotite zone mineral chemistry in Archean metasediments near Yellowknife, Northwest Territories, Canada. *Journal of Petrology*, 14, pp. 467-488.
- _____. 1973c. The origin of biotite in Archean metasediments near Yellowknife, N.W.T., Canada. *Contributions to Mineralogy and Petrology*, 42, pp. 43-54.

- _____. 1974. The cordierite isograd in Archean metasediments near Yellowknife, N.W.T., Canada--Variations on an experimentally established reaction. *Contributions to Mineralogy and Petrology*, 47, pp. 27-40.
- RAMSAY, C.R. and KAMINENI, D.C. 1977. Petrology and evolution of an Archean metamorphic aureole in the Slave Craton, Canada. *Journal of Petrology*, 18, 460-486.
- RASUMNY, J. 1957. Analyse microchimique des gas contenus dans les minéraux: formation du précipité barytique. *Compte Rendu sommaire des séances de la Société Géologique de France*, pp. 378-380.
- RASUMNY, J. 1960. Détection du gaz carbonique libre dans les minéraux. *International Geological Congress, 21st, Copenhagen 1960, Report, part 1*, pp. 27-29.
- ROEDDER, E. 1962. Studies of fluid inclusions: I. Low temperature applications of a dual purpose freezing and heating stage. *Economic Geology*, 57, pp. 1045-1061.
- _____. 1963. Studies of fluid inclusions. II. Freezing data and their interpretation. *Economic Geology*, 58, pp. 167-211.
- _____. 1967. Fluid inclusions as samples of ore fluids. In *Geochemistry of hydrothermal ore deposits. Edited by H.L. Barnes*. Holt, Rinehart and Winston, New York, pp. 515-574.
- _____. 1968-1977. (Editor). Fluid inclusion research: *Proceedings of COFFI, 1-10*. (Volumes 1-5 privately published; volumes 6-10 University of Michigan Press).
- _____. 1970. Application of an improved crushing microscope stage to studies of the gases in fluid inclusions. *Schweizerische Mineralogische und Petrographische Mitteilungen*, 50, pp. 41-58.
- _____. 1972. Composition of fluid inclusions. *U.S. Geological Survey, Professional Paper 440-JJ*, 164 p.
- _____. 1976. Fluid inclusion evidence on the genesis of ores in sedimentary and volcanic rocks. In *Handbook of strata-bound and stratiform ore deposits. Edited by K.H. Wolf*. Elsevier, Amsterdam, 2, pp. 67-110.

- _____. 1977. Fluid inclusions as tools in mineral exploration. *Economic Geology*, 72, pp. 503-525.
- _____. 1979. Fluid inclusions as samples of ore fluids. In *Geochemistry of hydrothermal ore deposits*. Edited by H.L. Barnes. 2nd edition. John Wiley and Sons, New York, pp. 684-737.
- _____. 1981. Origin of fluid inclusions and changes that occur after trapping. In *Short course in fluid inclusions: applications to petrology*. Edited by L.S. Hollister and M.L. Crawford. Mineralogical Association of Canada. pp. 101-137.
- ROEDDER, E. and BODNAR, R.J. 1980. Geologic pressure determinations from fluid inclusion studies. *Annual Review of the Earth and Planetary Sciences*, 8, pp. 263-301.
- ROEDDER, E. and KOPP, O. 1975. A check on the validity of the pressure correction in inclusion geothermometry using hydrothermally grown quartz. *Fortschritte der Mineralogie*, 52, pp. 431-446.
- ROEDDER, E. and SKINNER, B.J. 1968. Experimental evidence that fluid inclusions do not leak. *Economic Geology*, 63, pp. 715-730.
- ROSS, J.V. 1966. The structure and metamorphism of Mesa Lake map-area, District of Mackenzie, 86B/14 (west half). *Geological Survey of Canada, Bulletin 124*, 39 p.
- RYABOVA, T.V. 1973. On possibilities of use of properties of quartz for evaluation of ore mineralization in the Jurassic shaly complex of Dagestan. (Abstract) *Fluid Inclusion Research--Proceedings of COFFI*, 6, p. 136.
- RYE, D.M. and RYE, R.O. 1974. Homestake gold mine, South Dakota: I. Stable isotope studies. *Economic Geology*, 69, pp. 293-317.
- RYTUBA, J.J. and DICKSON, F.W. 1977. Reaction of pyrite + pyrrhotite + quartz + gold with NaCl-H₂O solutions, 300-500°C, 500-1,500 bars, and genetic implications. In *Problems of ore deposition*. Edited by B. Bogdanov. Fourth IAGOD Symposium, Varna, 1974. 2, pp. 320-326.
- SAWKINS, F.J., O'NEIL, J.R. and THOMPSON, J.M. 1979. Fluid inclusion and geochemical studies of vein gold deposits, Baguio district, Phillippines. *Economic Geology*, 74, pp. 1420-1434.

- SCHILLER, E.A. 1965. Mineral industry of the Northwest Territories, 1964. Geological Survey of Canada, Paper 65-11, 62 p.
- SEWARD, T.M. 1973. Thio complexes of gold and the transport of gold in hydrothermal ore solutions. *Geochimica et Cosmochimica Acta*, 37, pp. 379-399.
- SHEPHERD, T.J. 1977. Fluid inclusion study of Witwatersrand gold-uranium ores. *Philosophical Transactions of the Royal Society, London*, A286, pp. 549-565.
- SHILO, N.A., SIDOROV, A.A., GONCHAROV, V.I. and NAIBORODIN, V.I. 1971. The temperature conditions and the depths of formation of gold-ore deposits. *Society of Mining Geologists of Japan, Special Issue 3*, pp. 356-359.
- SORBY, H.C. 1858. On the microscopic structure of crystals, indicating the origin of minerals and rocks. *Quarterly Journal of the Geological Society (London)*, 14, (1) pp. 453-500.
- SPOONER, E.T.C. 1981. Fluid inclusion studies of hydrothermal ore deposits. *In* Short course in fluid inclusions: applications to petrology. *Edited by* L.S. Hollister and M.L. Crawford. Mineralogical Association of Canada, pp. 209-240.
- STEPHENSON, J.F. and EHMANN, W.D. 1971. Neutron activation analysis of gold in Archean igneous and metamorphic rocks of the Rice Lake-Beresford Lake area, Southeastern Manitoba. *Economic Geology*, 66, pp. 933-939.
- TAKENOUCHI, S. and KENNEDY, G.C. 1965. The solubility of carbon dioxide in NaCl solutions at high temperatures and pressures. *American Journal of Science*, 263, pp. 445-454.
- TAYLOR, F.C. and SCHILLER, E.A. 1966. Metamorphism of the Meguma Group of Nova Scotia. *Canadian Journal of Earth Sciences*, 3, pp. 959-974.
- TAYLOR, H.P., JR. 1979. Oxygen and hydrogen isotope relationships in hydrothermal mineral deposits. *In* Geochemistry of hydrothermal ore deposits. *Edited by* H.L. Barnes. 2nd edition. J. Wiley and Sons, New York, pp. 236-277.
- THOMPSON, P.H. 1978. Archean regional metamorphism in the Slave Structural Province--a new perspective on some old rocks. Geological Survey of Canada, Paper 78-10, pp. 85-102.

- THORPE, R.I. 1972. Mineral exploration and mining activities, mainland Northwest Territories, 1966-1968 (excluding Coppermine River area). Geological Survey of Canada, Paper 70-70, 204 p.
- _____. 1975. Geology of gold deposits in Canada. Geological Survey of Canada, Papers 75-1A, p. 256.
- TILLING, R.I., GOTTFRIED, D. and ROWE, J.J. 1973. Gold abundance in igneous rocks: bearing on gold mineralization. *Economic Geology*, 68, pp. 168-186.
- TREMBLAY, L.P. 1952. Giaque Lake map-area, Northwest Territories. Geological Survey of Canada, Memoir 266, 74 p.
- _____. 1976. Geology of northern Contwoyto Lake area, District of Mackenzie. Geological Survey of Canada, Memoir 381, 56 p.
- VERTUSHKOV, G.N. 1966. Moisture/gas ratio in gas-liquid inclusions in quartz and its importance in the study of vein deposits. *Akademiia Nauk SSSR, Doklady, Earth Science Sections*, 166, pp. 152-154.
- VERTUSHKOV, G.N., SOKOLOV, Yu.A., POPOV, V.A. 1970. Zhil'nyy kvarts nekotorykh zolotorudnykh mestorozhdeniy Urala. (Vein quartz of some gold deposits of the Urals) *Akademiia Nauk SSSR Uralskii Filial, Sverdlovsk, Institut Geologii i Geokhimii, Trudy*, 86, 38-43.
- VILJOEN, R.P., SAAGER, R. and VILJOEN, M.P. 1970. Some thoughts on the origin and processes responsible for the concentration of gold in the early Precambrian of South Africa. *Mineralium Deposita*, 5, pp. 164-180.
- WEISSBERG, B.C. 1970. Solubility of gold in hydrothermal alkaline sulfide solutions. *Economic Geology*, 65, pp. 551-556.
- WENNER, D.B. and TAYLOR, H.P., JR. 1971. Temperatures of serpentinization of ultramafic rocks based on O^{18}/O^{16} fractionation between coexisting serpentine and magnetite. *Contributions to Mineralogy and Petrology*, 32, pp. 165-185.
- WHITE, D.E. 1974. Diverse origins of hydrothermal ore fluids. *Economic Geology*, 69, pp. 954-973.

- WILLIAMS, G.J. 1965. Genetic review of pre-Tertiary gold mineralization. Eighth Commonwealth Mining and Metallurgical Congress, 1965. Australasian Institute of Mining and Metallurgy, Melbourne, 4, pp. 62-67.
- ZAKHAROVA, Ye.M. 1975. Mineraly ugleroda v rudakh Yeniseyskogo kriazha. (Minerals of the hydrocarbon group in ores of the Yenisey ridge.) Geologiya Rudnykh Mestorozhdenii, 17, (3), 114-120.

APPENDIX I

BRIEF NOTES ON THE GOLD OCCURRENCES STUDIED

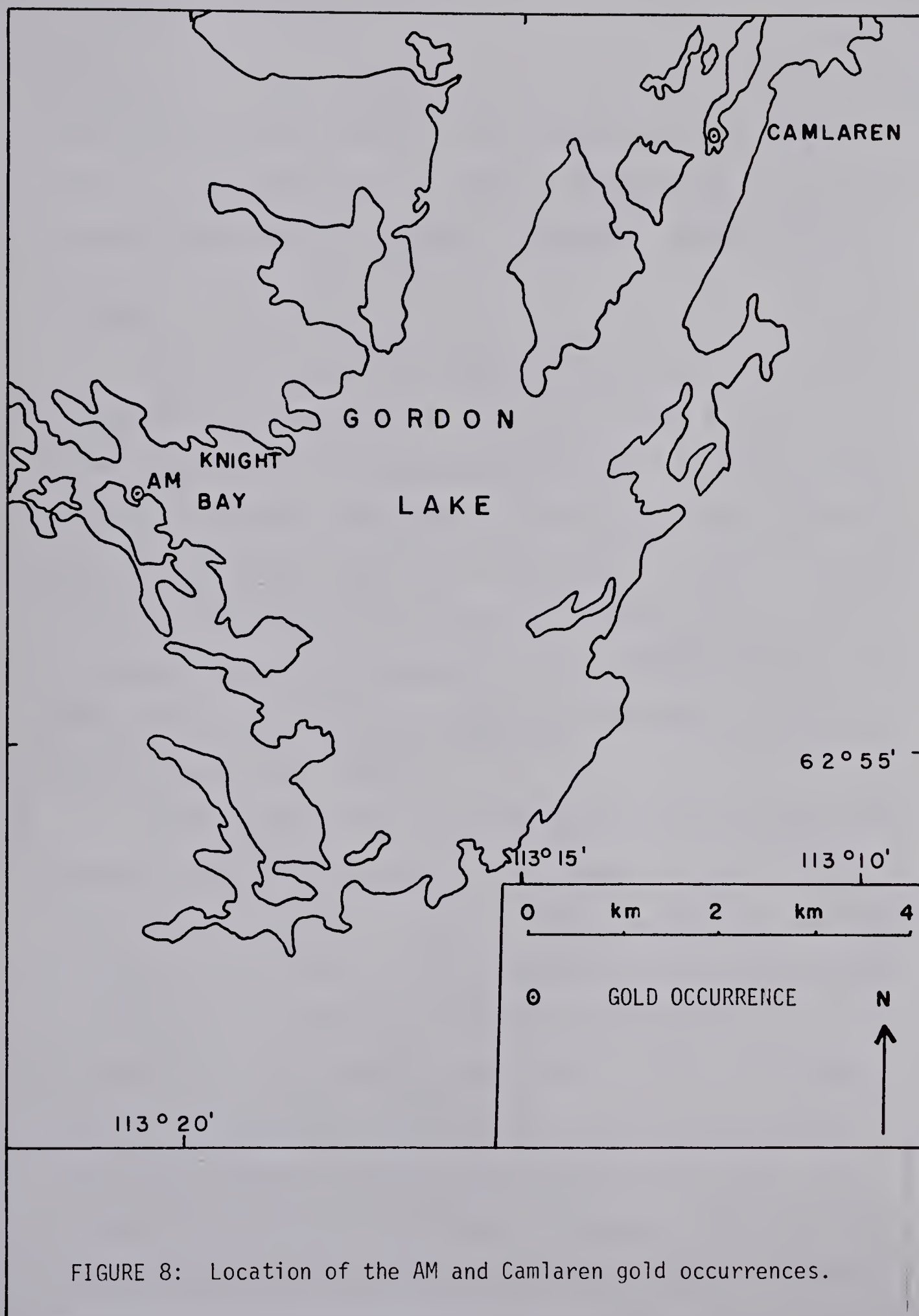
The following brief notes are compiled from various sources including field observations. Further information on these and other gold occurrences of the Yellowknife district, particularly details of their exploration and development history, can be found in the following references: Baragar 1961, 1962; Baragar and Hornbrook 1963, Boyle 1961, Gibbins et al. 1977, Henderson and Jolliffe 1939, Lord 1951, McGlynn 1971, Padgham et al. 1975, 1976; Schiller 1965 and Thorpe 1972.

Occurrences in Low Grade Metamorphic Rocks

AM

This occurrence is located on the southern shore of Knight Bay on the west side of Gordon Lake (Figure 8), approximately 75 km NE of Yellowknife. The property reportedly has five known gold showings (McGlynn 1971), of these the main East (#1) and West (#2) zones were examined. These vein systems outcrop on a small peninsula within the AM 1 claim and are exposed in eight small trenches.

The host rocks are isoclinally folded low grade metagreywackes and slates, with the bedding trending 110-130°. The quartz veins are subparallel to the bedding and appear to occur near the nose of plunging fold which is indicated to be a syncline by graded bedding. The East zone is about 50 m long and consists of quartz veins in a sheared zone up to 50 cm wide. This zone contains graphitic material

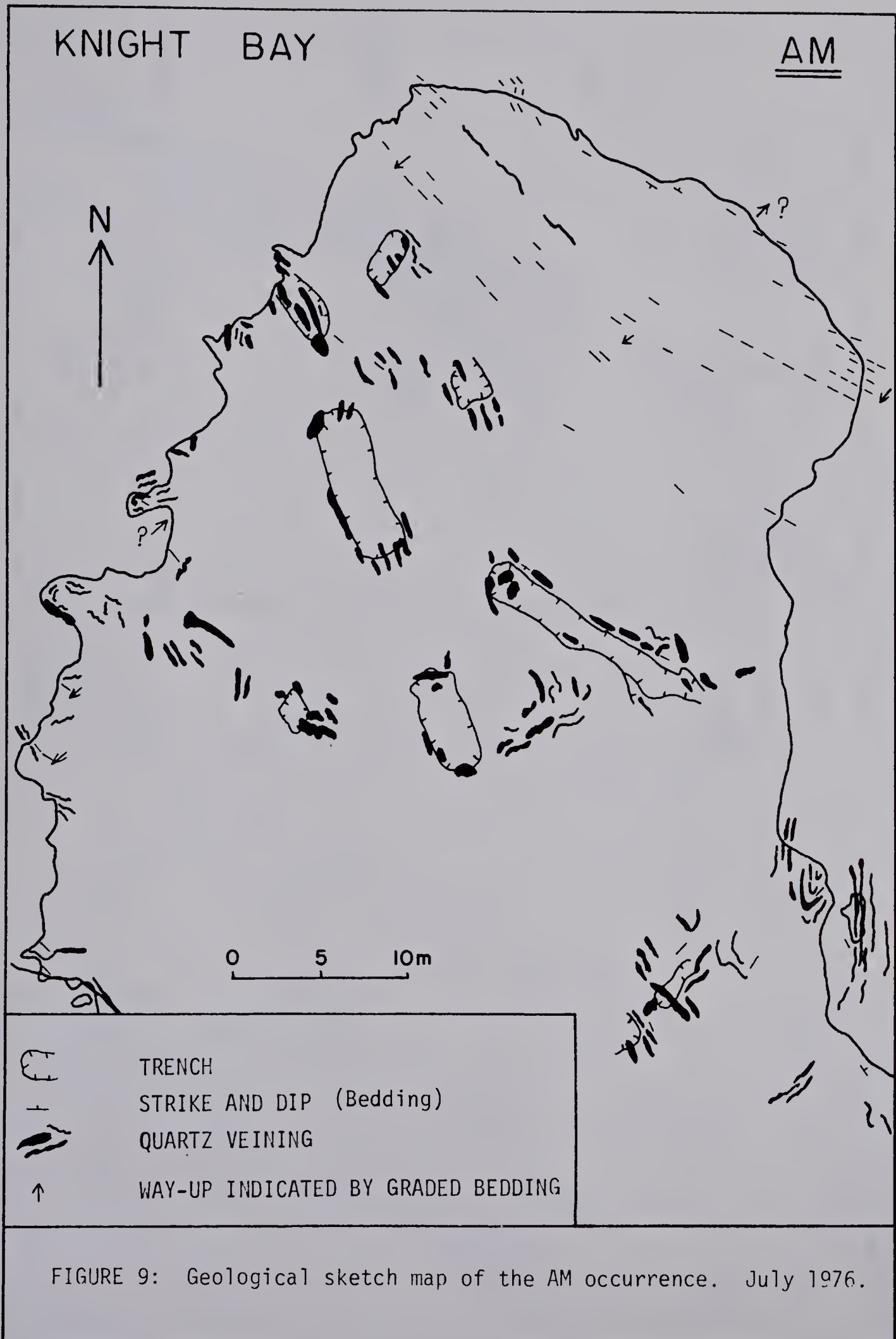


and the quartz is dark grey to bluish in colour. Minor pyrite, galena and visible gold were observed, while arsenopyrite and sphalerite have also been reported (McGlynn 1971). The West zone, about 70 m long and 30-50 cm wide, is similar in character. (See Figure 9).

Camlaren

The Camlaren mine is situated approximately 85 km NE of Yellowknife on the east side of Gordon Lake (Figure 8). The property is underlain by low grade metagreywackes and slate in which numerous quartz veins, parallel to bedding, occur. The host rocks are isoclinally folded and strike $020-045^{\circ}$. First developed in the late 1930's the mine has recently reopened. At the time of visiting however the mine was closed and samples, some containing visible gold along with pyrite, galena and sphalerite, were collected from the 'ore' stockpile.

There are three main auriferous quartz veins delineated, the most important of which is the Hump vein (Henderson and Jolliffe 1939). This vein occurs in a zone of thinly bedded slate and meta-greywacke, in part paralleling the bedding and part concentrated in the nose of a fold which plunges steeply to the NE (Figure 10). The vein is 1-1.5 m at surface, though widens to 6 m in the saddle of the fold. The quartz is light blue-grey in colour and graphite-coated shear surfaces have been noted within the vein and at its contacts (Henderson and Fraser 1948). The gold is generally associated with the sulphides (which constitute less than one percent of the vein); chalcopyrite has also been reported.



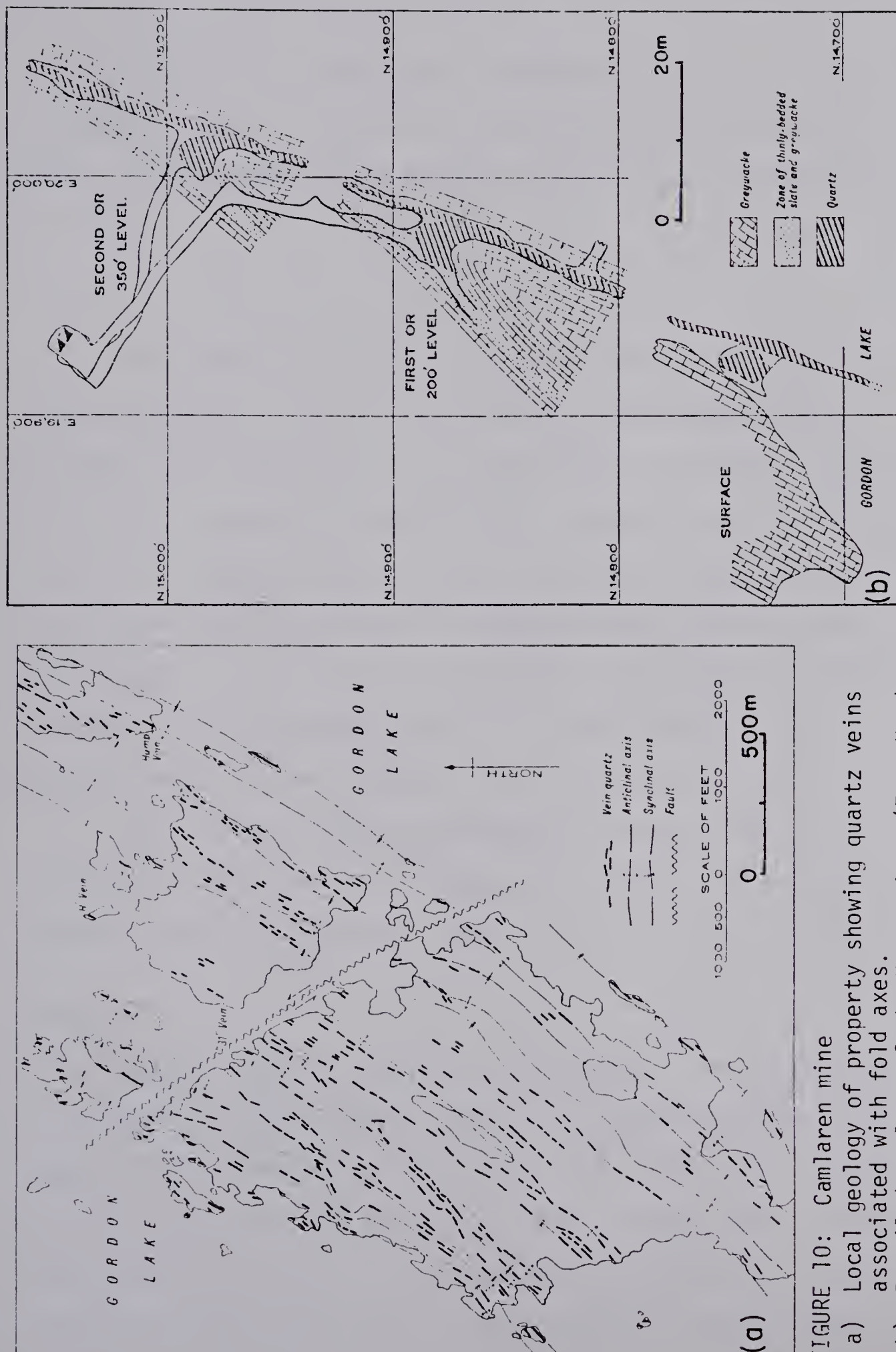


FIGURE 10: Camlaren mine

- a) Local geology of property showing quartz veins associated with fold axes.
- b) Detailed geology of the Hump vein. (From Henderson and Jolliffe 1939).

In the early sixties about 12,000 tons of ore was milled, grading just over 1 oz. per ton. As of 1975, reserves were estimated at 56,000 tons grading 0.62 oz. per ton of gold (Gibbins et al. 1977).

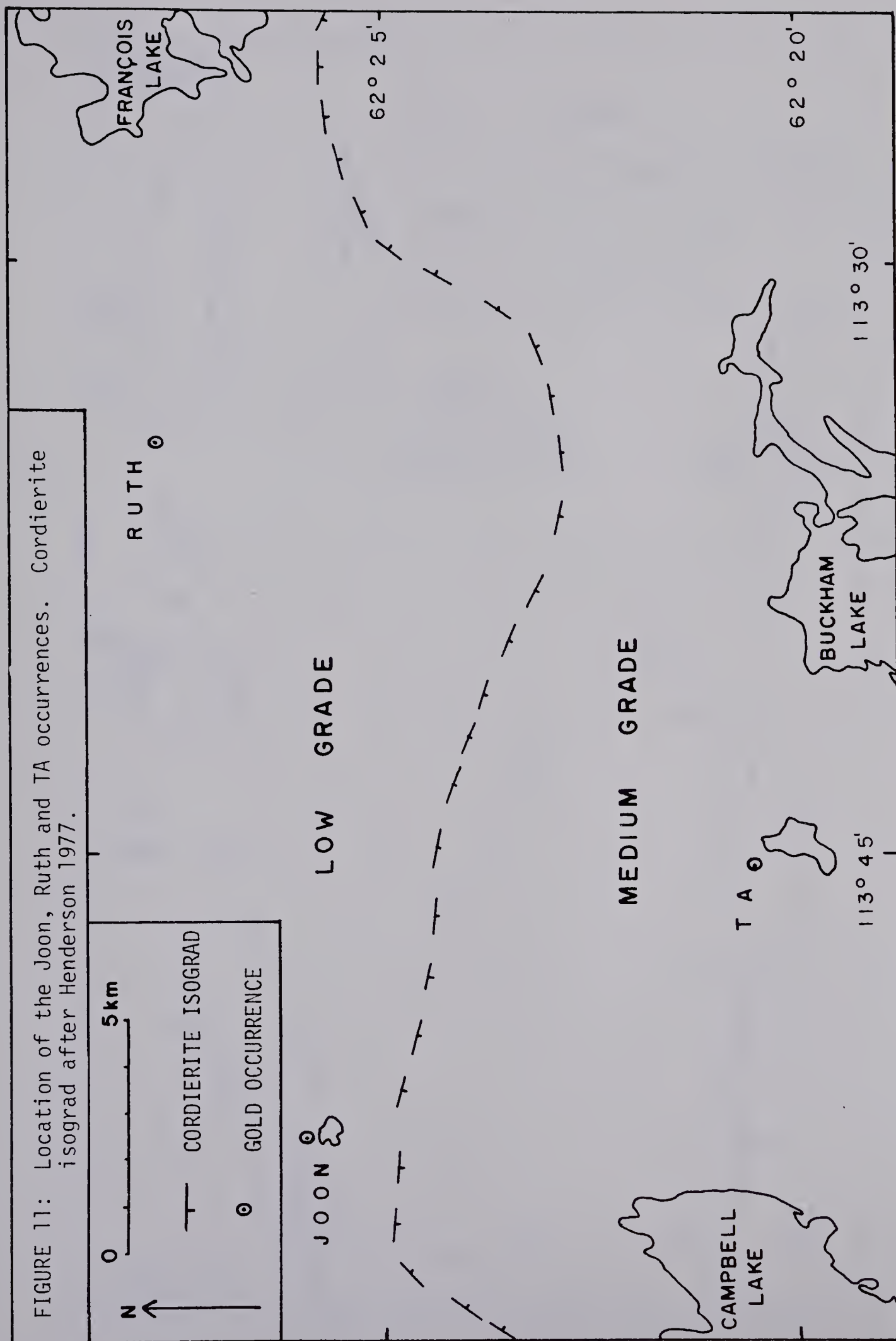
Joon

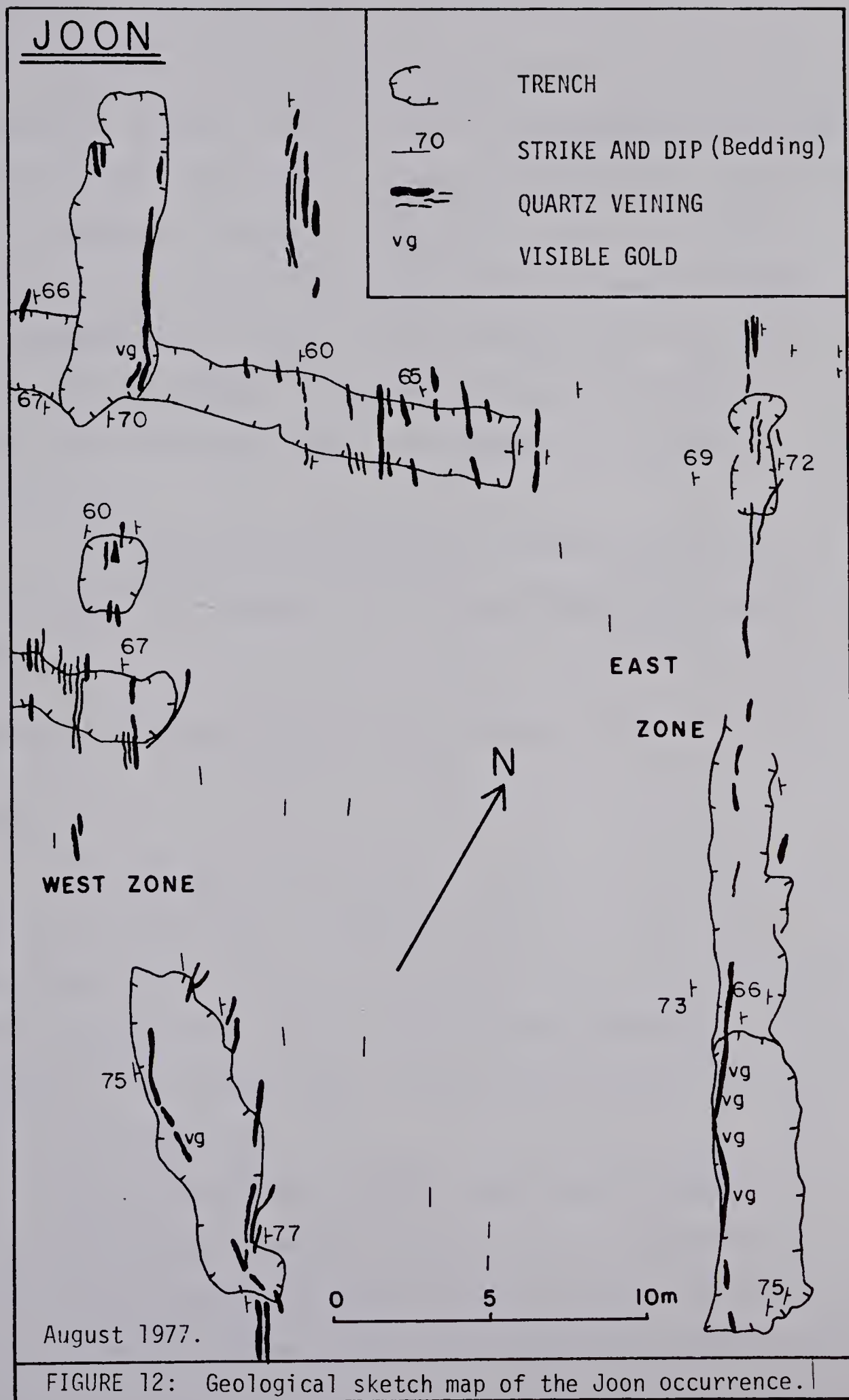
This occurrence is about 75 km E of Yellowknife, immediately N of "Strike Lake". The host rocks are low grade metagreywacke and slate which strike 140-150° and dip steeply to the east. The mineralization occurs in two main zones: the West zone, ~60 m by 5 m and the East zone ~30 m by 0.5 m, at surface. These consist of narrow quartz veins subparallel to the bedding and associated with minor shearing in a graphitic slate horizon. The quartz is blue-grey in colour and contains minor pyrite and visible gold which are mainly found at the vein contacts. (See Figures 11 and 12).

'Ore' reserves have been estimated at about 2,000 tons grading 2 oz. of Au per ton (Padgham et al. 1976) and in the late seventies production amounted to 300 oz of Au from hand sorted ore.

Ruth

Located nearly 95 km east of Yellowknife, the Ruth property is underlain by steeply dipping folded, low grade metagreywacke and slate. There are over 90 trenches on six veins within the property but most development work has been on three of these veins. In this study samples for fluid inclusion study were collected from one of these three veins, the #2 vein, in the vicinity of the old shaft.





The #2 vein is hosted by steeply dipping strata which strike $000-020^{\circ}$ and face east (indicated by well-developed graded bedding). The vein subparallels the bedding, occurs mainly within a slate horizon and is exposed for some 400 m, being 30-40 cm wide. Wall rock alteration is very minor there being slight development of biotite and arsenopyrite. The quartz is fine grained, white to grey in colour, with occasional biotite inclusions and contains minor pyrite and visible gold. Lord (1951) recorded the presence of scheelite also.

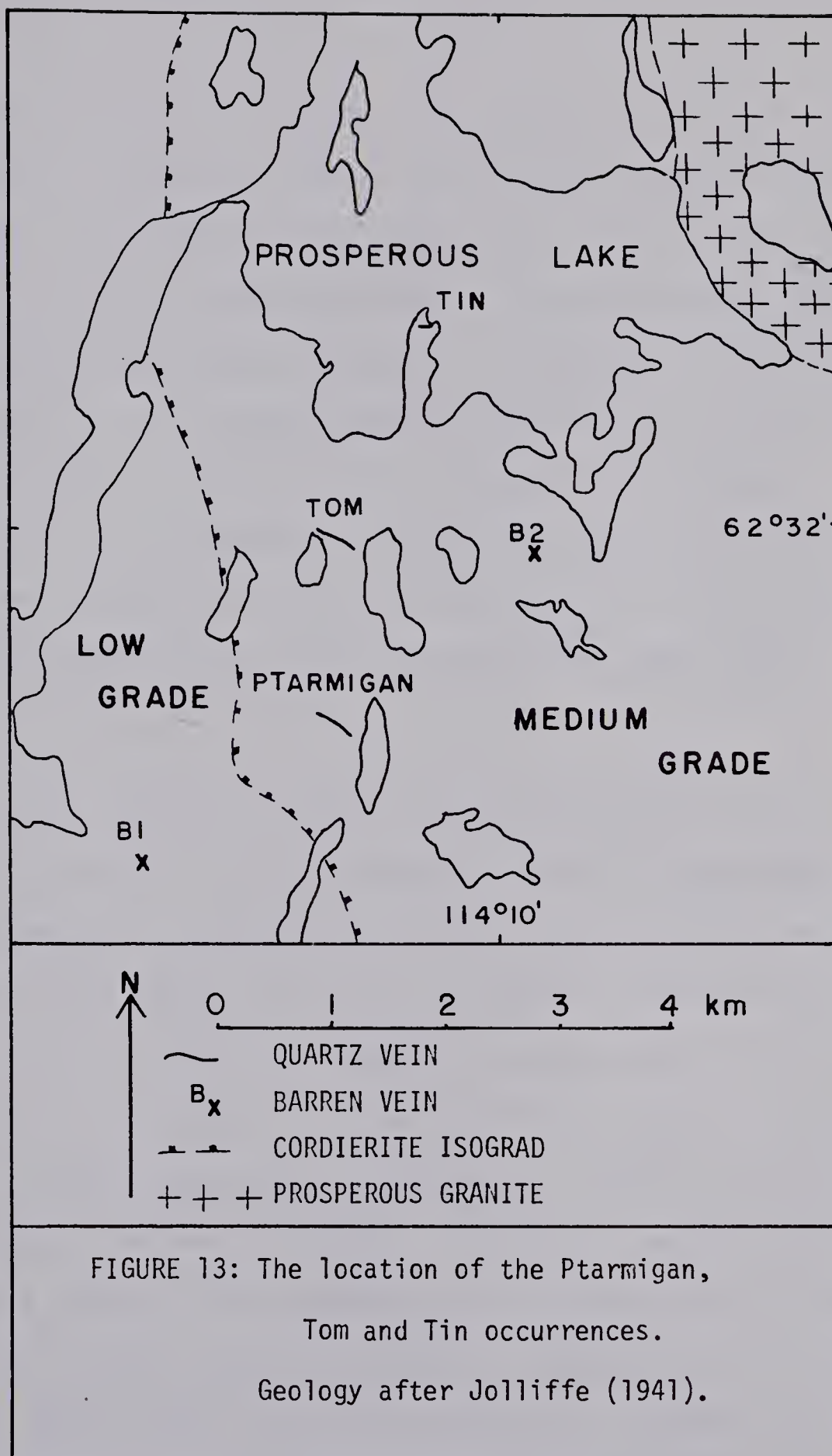
The #2 vein has been estimated to contain approximately 2,500 tons of 'ore' grading 2.2 oz of Au per ton (Padgham et al. 1976).

Occurrences in Medium Grade Metamorphic Rocks

Ptarmigan

The Ptarmigan mine is situated 10 km NE of Yellowknife, south of Prosperous Lake. A number of quartz veins occur en echelon hosted by a quartz mica schist, the higher grade equivalent of the metagreywacke and slate. Relict bedding indicates a strike of about 170° for these rocks; they dip steeply east and are overturned. (See Figure 13).

The main auriferous vein (#1) cuts across the bedding, striking at 115° and is exposed discontinuously for 400 m and averages 4 m in width. The quartz is mainly light to dark grey, coarse grained and vitreous. Even in hand specimen it can often be



seen that the colour is caused by disseminated black specks. Milky white quartz veinlets also occur; Boyle (1961) considered these to be later than the grey, glassy quartz but as Ramsay (1973a) noted the relationship is not always clear. Tourmaline and well developed biotite occur sporadically along the vein contacts. Visible gold is generally associated with sulphide mineralization; pyrite, galena and sphalerite are the most common. Boyle (1961) recorded arsenopyrite, chalcopyrite and pyrrhotite as well, along with scheelite. During 1941-1942 about 35,000 tons of ore were milled, averaging approximately 0.34 oz. of Au per ton (Lord, 1951).

Tom

This property is just N of the Ptarmigan mine, some 12 km from Yellowknife. The mineralization is hosted by quartz mica schist; relict bedding is steeply dipping and strikes $170-180^{\circ}$, indistinct graded bedding suggests the strata face west. (See Figure 13).

The main auriferous vein (#3) is very similar to the Ptarmigan veins and may represent a continuation of that system. The vein outcrops for approximately 400 m and averages 2 m wide; it crosscuts the bedding, striking at $110-120^{\circ}$. The quartz is white to dark grey in colour and varies from saccharoidal to coarse-grained. Pyrite, galena and visible gold were observed in samples taken from a small dump around the shaft. Wall rock alteration is limited to the development of coarse biotite, pyrite and traces of pyrrhotite. Minor quartz-tourmaline veinlets occur alongside the main vein, they are discontinuous and irregular and their relationship to the

main vein is uncertain.

Tin

The Tin occurrence is on the south shore of Prosperous Lake, about 13 km NE of Yellowknife. The host rock is quartz mica schist which exhibits bedding which strikes $010-030^{\circ}$ and the beds dip steeply to the west. The mineralization is largely within a 1 m thick, yellow-weathering sericite schist perhaps representative of a small shear or fault which crosscuts the bedding. Massive dark grey to black sphalerite is common and occurs along with ankerite, minor pyrite and traces of visible gold and pyrrhotite. The presence of chalcopyrite is suggested by minor malachite staining. Associated with this mineralization, which is exposed in a trench about 10 m long, are numerous subparallel veinlets of white to dark grey quartz. Outside of the sericite schist zone these veins are edged with well-developed biotite. No production is reported from this small showing. (See Figure 13).

TA

The TA property is situated 84 km ESE of Yellowknife, just north of Bullmoose Lake. The country rocks vary from coarse-grained quartz mica schist to finer grained biotite schist representing the metamorphosed equivalents of greywacke and shale. (See Figure 11).

Seven main veins occur on the property but most of the development work was carried out on the #4 vein and this is the one that was sampled. The vein strikes approximately 165° and dips

steeply to the east, parallel with the bedding. It occurs at the contact between a quartz mica schist and a finer grained biotite schist; minor shearing is exhibited all along the vein. South of an old shaft the vein averages 10 cm in width, ranging up to 30 cm; north of the shaft it is wider, 2-5 m, though is partially obscured by rubble. Overall length is about 150 m. The quartz varies from a fine-grained white type to a dark grey vitreous variety; pyrite and traces of visible gold were the only metallic minerals noted. Wallrock alteration is limited to the development of coarse-grained biotite. Production has been limited to a little hand-sorted ore in 1940-1941 (Lord 1951).

Hidden Lake

This showing is located 45 km ENE of Yellowknife, north of the east end of Hidden Lake. The country rocks consist of thinly bedded quartz mica schists which strike $150-170^{\circ}$ and dip at $25-30^{\circ}$ east. Little is visible at surface, but underground development work indicates the mineralization is found in a series of quartz boudins which subparallel the bedding (Schiller 1965). Reported metallic minerals are pyrite, galena, chalcopyrite and visible gold. Tourmaline and biotite occur as alteration minerals at the margins of the quartz veins. Samples were collected from several small pits about 20 m W of an old shaft. Drilling results suggest the mineralization is of very limited extent (Padgham et al. 1976).

Barren veins

Numerous small, irregular bodies of vein quartz occur in the metasediments in the Yellowknife area; as far as is known they do not contain any gold mineralization and are thought to have formed during metamorphism (Boyle 1961, Ramsay 1973a). In a study of quartz from these veins Ramsay (1973a) determined a main range of Th of 210-270°C for primary inclusions and of 115-165°C for secondary inclusions. No freezing studies were performed but he noted that many of the secondary inclusions were saturated at room temperature; he suggested that the primary inclusions were slightly undersaturated. The types of inclusions that he noted are broadly similar to those observed in this study.

APPENDIX II

FLUID INCLUSION METHODOLOGY

Instrumentation

The equipment used in this study was a Chaixmeca micro-thermometry apparatus (model VI 2120) specifically designed for the study of fluid inclusions. It consists of a combined heating and freezing stage, with sample chamber, and a console with temperature read-out and controller.

The bronze alloy stage is heated using an annular resistance heating coil; cooling is achieved by a flow of nitrogen gas through the stage. The gas is first cooled by passing it through a copper coil within a liquid nitrogen bath. The stage contains a platinum resistance thermal sensor which is connected to a digital voltmeter having a resolution of 0.1°C . The equipment can be used in the range -180°C to $+600^{\circ}\text{C}$.

The heating-freezing stage is attached to a Leitz microscope and is used with 5x, 10x, 20x, 32x and 40x lenses, and 25x and 10x oculars. The 20x and 32x lenses have been fitted with water jackets so that they can be cooled by circulating water during high temperature use of the stage.

A plastic sleeve can be fitted between the lens and the sample chamber to improve insulation and decrease frosting when using the stage at low temperatures. Illumination of the fluid inclusion samples may be improved by using an American Optical

Corporation flexible fibre-optics illuminator.

A small black and white television camera has been fitted to the microscope so that the inclusions under observation can be displayed on a television screen. This increases operator efficiency by reducing eyestrain, though optical resolution is slightly poorer. When precise observations are necessary the microscope is used directly.

Poty et al. (1976) describe and illustrate a similar microthermometry apparatus. Tests they carried out at 380°C indicate a vertical gradient of 0.9 to 1.0°C over a distance of up to 1 mm above the heating stage. At this temperature tests show that in the optic field of the stage the horizontal thermal gradient was not more than 0.8°C from the centre of the optic field to its edge.

For future studies it would be worthwhile to follow the modifications of Cunningham and Carollo (1980). These include the use of a water jacket for the microscope lens (as has been done), alteration of the sample chamber and thermal insulation of the stage. The modifications result in improved optical resolution, decreased thermal gradients and a more linear calibration curve.

For prolonged use of the stage at high temperatures it would be beneficial to obtain the gold-coated stage available from Chaixmeca. This prevents oxidation of the stage which otherwise may occur under such conditions.

Calibration

Good precision can be achieved using the microthermometry techniques under standard operating procedure. An indication of the possible reproducibility of results is given in Figure 14.

However, to attain accuracy it is necessary to calibrate the instrument. This is done by measuring the melting point of high purity compounds. Surprisingly few compounds are suitable for use: many substances having melting points within the range of interest, dissociate or melt incongruently on heating and some compounds give poor reproducibility due to hydration. The standards chosen and used are listed in Table 3. Jehl (1975, Annex III) discusses calibration and the choice of standards at some length.

For determination of the melting points the standards were sealed within glass capillary tubes. Mainly square and rectangular cross-section capillary tubes of 0.2-0.5 mm internal diameter were used as it was thought these would best approximate fluid inclusion samples, and give better thermal contact than capillary tubes with a circular cross-section.

Sealing the compounds within the glass tubes was a problem, particularly with the volatile organic liquids. In an attempt to solve this a carbon dioxide laser (designed for surgery) was used to fuse and seal the capillaries. The laser provided a high temperature point source of heat, and facilitated rapid fusing of the glass with diminished loss of the compound by

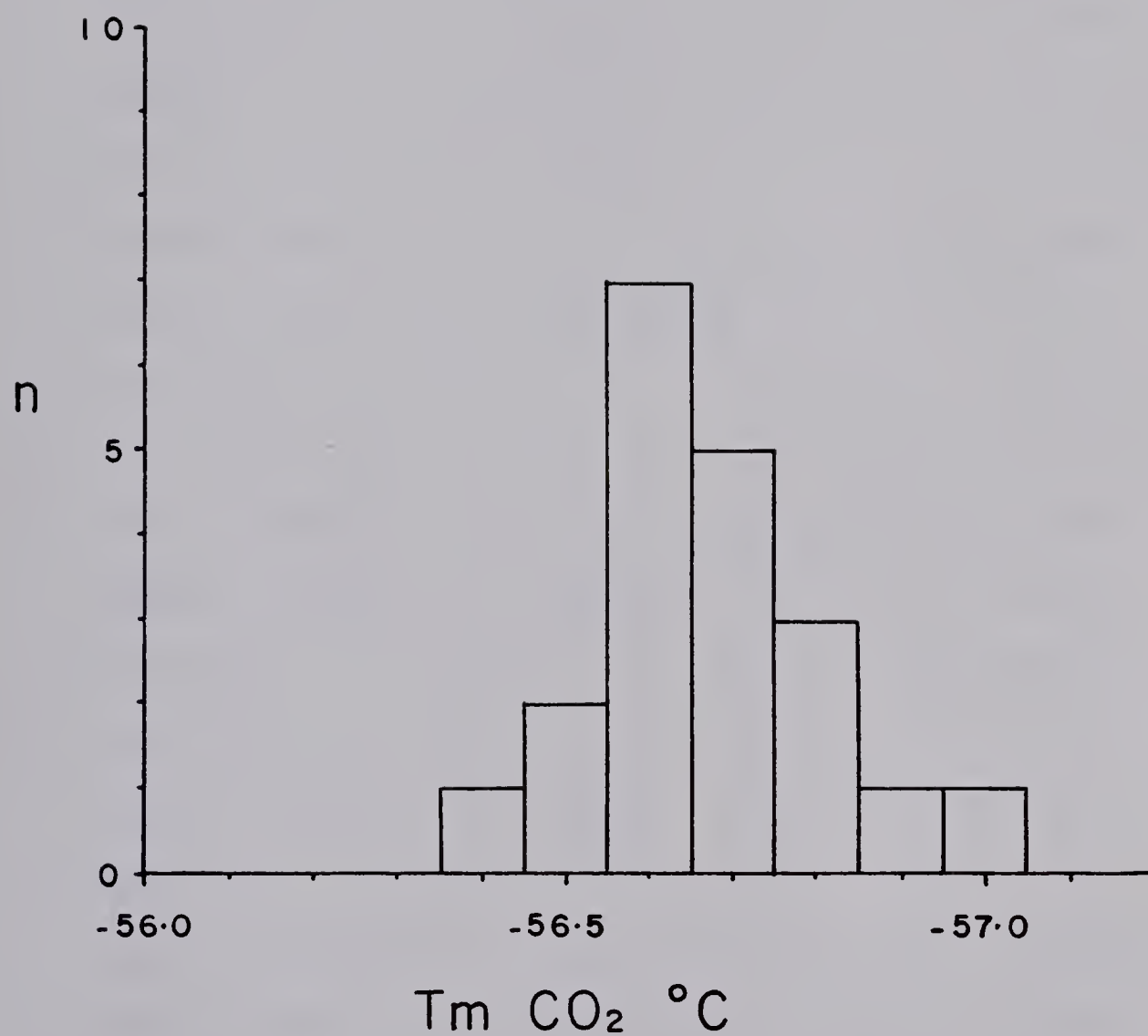


FIGURE 14: Microthermometric stage reproducibility. Plot of 20 measurements of $T_m\text{CO}_2$ for a single three-phase inclusion in quartz from Camperio, Switzerland. This is an interlaboratory standard and the value of -56.6°C (the triple point of CO_2) is assigned to the peak.

TABLE 3
MOCROTHERMOMETRY CALIBRATION STANDARDS

Name	Formula	Melting Temperature °C
a) cyclohexene	C_6H_{10}	-103.5
b) heptane	C_7H_{16}	- 90.61
c) octane	C_8H_{18}	- 56.79
d) CO_2 inclusion	CO_2	- 56.6
e) ethylene glycol	$HOCH_2CH_2OH$	- 11.5
f) Merck 9670	?	+ 70
g) Merck 9700	?	+100
h) tin terraoxide	SnI_4	+144.5
i) ammonium nitrate	NH_4NO_3	+169.6
j) Merck 9780	?	+180
k) Merck 9800	?	+200
l) mercuric bromide	$HgBr_2$	+236
m) Merck 9847	?	+247
n) antimony trifluoride	SbF_3	+292
o) sodium nitrate	$NaNO_3$	+306.8
p) arsenic trioxide	As_2O_3	+315
q) anhydrous sodium acetate	$NaOOCCH_3$	+324
r) potassium dichromate	$K_2Cr_2O_7$	+398
s) thallium bromide	$TlBr_2$	+480

volatilization. Although results were further improved by first freezing the volatile compounds, proper sealing was difficult to attain.

The outside diameters of the capillaries were very close to the average thickness of the fluid inclusion samples, therefore vertical temperature gradients within the heating-freezing stage could be disregarded. Horizontal gradients were minimized by considering only that part of the standard located in the optic centre of the stage. The operating procedure used during calibration (i.e. stage and sample positioning, heating rate, lens, flow rate for water jacket, illumination, etc.) was as close as possible to that used during subsequent examination of the fluid inclusion samples.

A heating rate of 0.25°C per minute was used within 10°C of the target temperature. This approaches static heat-flow conditions and results in lower thermal gradients and reduced errors (Roedder, 1976).

The temperature of melting of the last solid at the optic centre of the stage was taken to be the melting point. This limits the influence of impurities which generally lower the melting point of a substance. Several readings were taken on each standard to check on reproducibility of results.

The results are plotted in Figure 15 as a calibration curve. Figure 16 clearly shows the correction factor that must be applied at any given, recorded temperature. This figure also

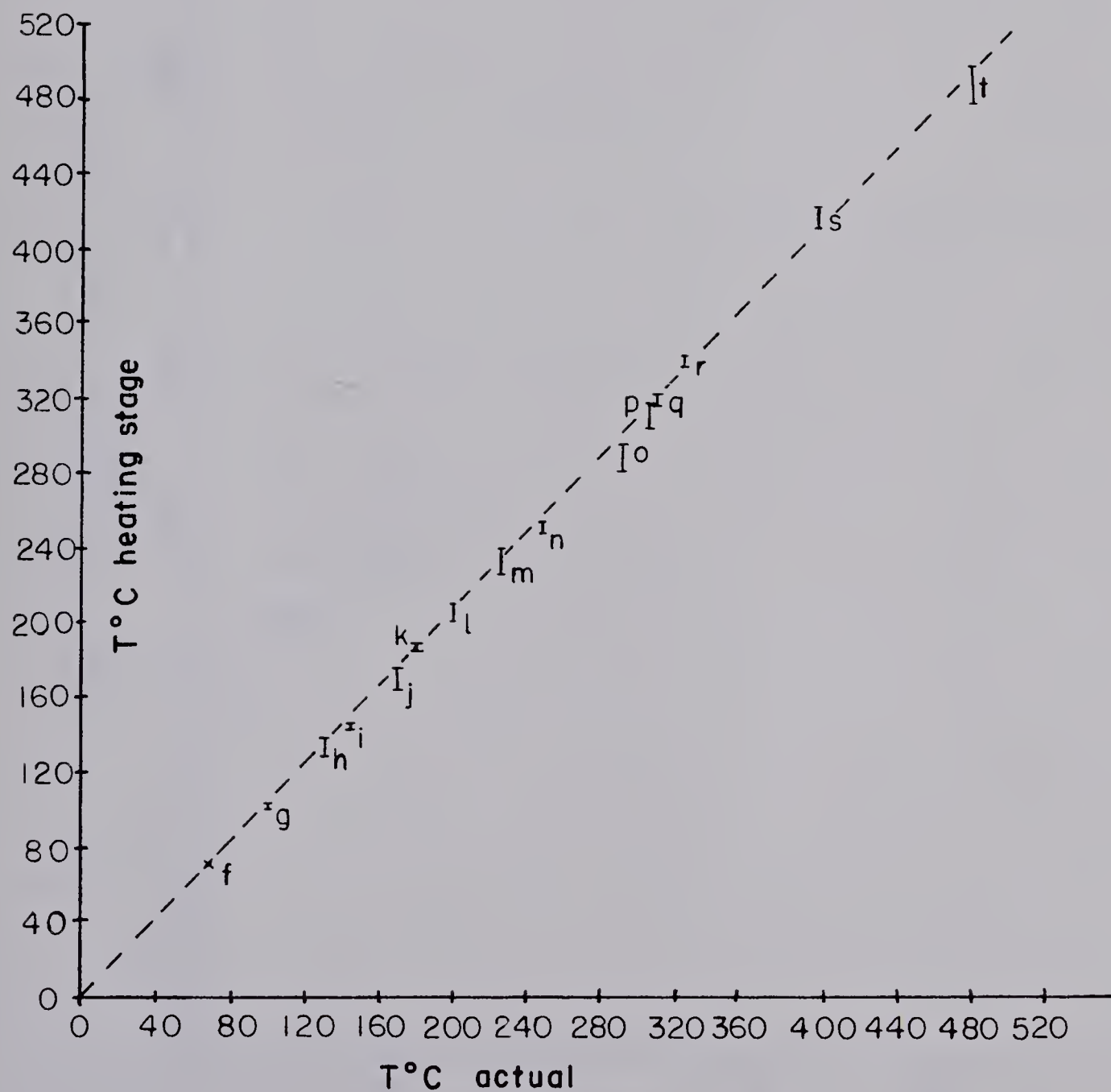
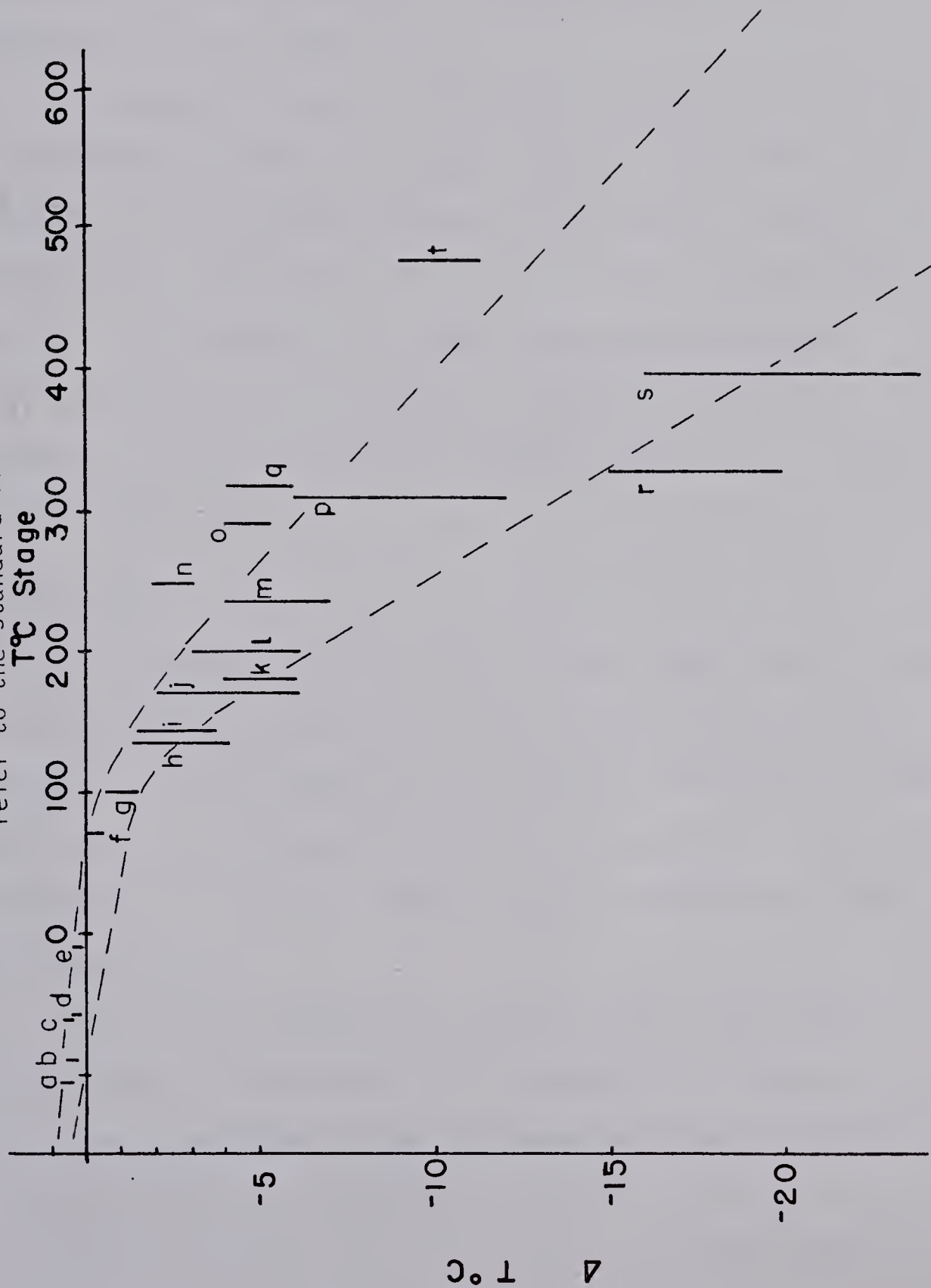


FIGURE 15: Calibration curve for the heating stage. Letters refer to the standards listed in Table 3.

FIGURE 16: Calibration curve showing correction values. Letters refer to the standard listed in Table 3.



demonstrates the decreased reproducibility at high temperatures which is due to the difficulty of achieving low, controlled heating rates at such temperatures.

Discussion of the practicalities of calibrating and using microthermometric equipment is widely dispersed in the literature and often in less accessible sources such as theses. However Roedder (1976) covers some aspects with particular regard to ore deposits and, fortunately, in a recent paper Hollister et al. (1981) compile and review available information. This latter reference is strongly recommended to anyone embarking on a fluid inclusion study.

Crushing Method

Minute grains from the fluid inclusion samples were crushed in a crushing stage while being examined through the petrographic microscope. As first described by Deicha (1950) this method allows the detection of gas under high pressure in fluid inclusions. An adaptation of the technique enables qualitative determination of the gas(es) present.

The crushing stage used is similar to that described by Roedder (1970); he gives details of the design and operation of such a stage. The method allows the detection of the presence of as little as 10^{-14} g of noncondensable gas and the estimate of the confining pressure if the volumes of the gas bubble before and after crushing are compared. Varying the crushing medium can indicate the nature of the gas released upon crushing.

The samples were first crushed in anhydrous glycerine. H_2O is instantly absorbed by the glycerine but CO_2 and many hydrocarbons are insoluble and are visible as small bubbles. By then crushing samples in barium hydroxide solution CO_2 can be identified (Rasumny 1957, 1960). The barium hydroxide reacts with any CO_2 released from the inclusions forming a white precipitate. Alternatively an alkaline barium chloride solution can be used to detect CO_2 (Roedder, 1970). Finally the samples are crushed in CO_2 -saturated kerosene; this absorbs hydrocarbons, but not CO_2 which will form small bubbles in the liquid.

Further details of the technique are given in Roedder (1970, 1972). It is worth noting his caution that, with such small volumes of gas, an "insoluble" gas may dissolve in the liquids used--though more slowly than a soluble gas.

The results of the crushing experiments are presented in Table 4.

TABLE 4
CRUSHING RESULTS--GAS EVOLUTION

<u>Sample No.</u>	<u>Crushing Fluid</u>		
	a) Anhydrous Glycerine	b) CO ₂ saturated Kerosene	c) Barium Hydroxide
AM			
A1	Minor	No	No
A2	Moderate	No	No
A3	Minor	No	No
A5	Abundant	Minor	No
A6	Moderate	Moderate	Minor
A7	Minor	Minor	No
A8	Moderate	Minor	No
A10	Moderate	Moderate	No
A11	Minor	Minor	No
A12	Abundant	Abundant	Minor
A14	Abundant	Moderate	No
Camlaren			
C1	Abundant	Abundant	Minor
C2	Minor	Minor	No
C3	Moderate	Moderate	No
C4	Abundant	Minor	No
C5	Abundant	Moderate	Minor
C6	Moderate	Minor	No
C8	Minor	Minor	No
C9	Moderate	Moderate	No
C10	Minor	Minor	Minor
C11	Minor	Minor	No
C12	Moderate	Minor	No
C13	Minor	No	No
Joon			
J1	Minor	Minor	No
J2	Moderate	Minor	No
J3	No	No	No
J4	Moderate	Minor	No
J5	Abundant	Moderate	Moderate
J6	Minor	No	No
J7	Moderate	Moderate	Minor
J8	Minor	No	No
J10	Moderate	No	No

<u>Sample No.</u>	<u>Crushing Fluid</u>		
	a) Anhydrous Glycerine	b) CO ₂ saturated Kerosene	c) Barium Hydroxide
Ruth			
R2	Abundant	Moderate	Minor
R3	Moderate	Minor	Minor
R4	Minor	No	No
R6	Minor	Minor	No
R7	No	No	No
R8	Minor	No	No
R9	Moderate	Minor	No
R10	Moderate	Minor	Minor
Ptarmigan			
P1	Minor	No	No
P3	Abundant	Minor	Minor
P4	Moderate	Minor	No
P5	Minor	No	No
Tom			
T1	Moderate	Moderate	Minor
T3	Minor	No	No
T4	Moderate	Minor	No
Tin			
S1	Moderate	Minor	No
S1	Moderate	No	No
TA			
D1	Moderate	Minor	No
D4	Abundant	Moderate	Minor
D5	Minor	No	No
D6	No	No	No
D8	Moderate	No	No
Hidden Lake			
H1	Abundant	Moderate	Minor
H2	Minor	No	No
H3	No	No	No
H5	Moderate	Minor	No
H6	Moderate	Minor	Minor
H7	Abundant	Minor	No
H9	No	No	No
H11	Minor	No	No

a) High pressure gas indicator

b) CO₂ indicator

c) CO₂ indicator

} Together may indicate hydrocarbons

APPENDIX III
FLUID INCLUSION SALINITY DATA

Locality and Sample Number	Inclusion Class	Number Measured	Tm ⁰ C Range	Wt.% NaCl Equivalent
<u>AM</u>				
A1	P	2	-3.2 to -3.7	5.4 - 6.2
	S	2	-5.4 to -6.7	8.5 - 10.1
A2	P	3	-2.6 to -5.1	4.3 - 8.1
	S	2	-7.5 to -13.4	11.1 - 17.2
A3	P	1	-1.9	3.2
	S	3	-.68 to -15.6	10.3 - 19.2
A5	P	2	-2.0 to -2.4	3.4 - 4.0
	S	3	-6.0 to -11.2	9.3 - 15.2
A6	P(?)	1	-1.0	1.7
	S	2	-6.1 to -6.7	9.4 - 10.2
A7	P	2	-1.9 to -2.3	3.1 - 3.8
	S	3	-16.9 to -19.2, +155	20.3 - 30
A8	P	1	-3.0	4.9
	S	2	-12.2 to -15.0	16.1 - 18.7
A10	P	3	-2.9 to -3.5	4.7 - 5.8
	S	3	-4.5 to -9.3	7.2 - 13.3
A12	P	1	-2.6	4.2
	S	2	-5.1 to -11.4	8.1 - 15.4
A14	S	2	-3.7 to -9.2	6.1 - 13.2
<u>Camlaren</u>				
C1	P	1	-1.5	2.4
	S	2	-5.7 to -6.7	8.9 - 10.1
C2	P	1	-2.3	3.8
	S	2	-6.0 to -6.8	9.2 - 10.3
C3	S	2	-5.2 to -10.0	8.2 - 14.1
C4	P	2	-3.7 to -7.2	6.2 - 10.7
	S	3	-6.5 to -8.5	9.9 - 12.3
C5	P	1	-2.4	4.0
	S	2	-6.7 to -8.0	10.1 - 11.8
C6	S	2	-4.8 to -5.2	7.6 - 8.2
C8	P	1	-2.9	4.8
	S	1	-7.7	11.4
C9	P	2	-2.0 to -3.7	3.4 - 6.2
	S	3	-3.8 to -9.2	6.3 - 13.1
C10	P	1	-14.3	18.1
	S	3	-6.7 to -10.1	10.2 - 14.1

Locality and Sample Number	Inclusion Class	Number Measured	Tm ⁰ C Range	Wt.% NaCl Equivalent
C11	P	2	-2.6 to -3.8	4.2 - 6.3
	S	2	-6.0 to -8.3	9.2 - 12.1
C12	P(?)	1	-9.0	13.0
	S	2	-7.3 to -7.7	10.9 - 11.3
C13	P	2	-2.4 to -3.3	3.9 - 5.5
	S	1	-16.8	20.2

Joon

J1	P	1	-3.1	5.1
	S	2	-6.0 to -7.6	9.3 - 11.2
J2	P	2	-3.0 to -3.7	4.9 - 6.1
	S	3	-7.7 to -12.2	11.4 - 16.1
J3	P	2	-2.9 to -8.3	4.8 - 12.1
	S	2	-6.0 to -14.4	9.3 - 18.2
J4	P	1	-6.9	10.4
	S	2	-8.6 to -9.5	12.4 - 13.5
J5	P	1	-3.8	6.3
	S	2	-4.5 to -10.2	7.2 - 14.2
J6	P	2	-1.3 to -1.7	2.1 - 2.8
	S	2	-14.5 to -15.9	18.3 - 19.4
J7	S	1	+143	29
J8	P	1	-4.4	7.1
	S	2	-15.7 to -19.2	19.3 - 22.1
J10	P	1	-2.3	3.8
	S	3	-5.7 to -8.3	8.9 - 12.1

Ruth

R2	P	1	-2.3	3.7
	S	2	-5.5 to -6.8	8.6 - 10.3
R3	S	1	-8.3	12.1
R4	P	1	-3.4	5.6
	S	2	-6.9 to -11.1	10.4 - 15.1
R6	P	2	-3.0 to -3.5	4.9 - 5.8
	S	3	-12.2 to -15.7	16.1 - 19.3
R7	P	1	-4.4	7.1
	S	2	-6.0 to -6.2	9.3 - 9.5
R8	P	1	-6.7	10.2
	S	2	-5.3 to -8.3	8.4 - 12.1
R9	P	1	-2.5	4.1
	S	3	-6.7 to -18.1	10.1 - 21.3
R10	P	2	-2.3 to -2.4	3.8 - 3.9
	S	2	-6.1 to -7.6	9.4 - 11.2

Locality and Sample Number	Inclusion Class	Number Measured	Tm ⁰ C Range	Wt.% NaCl Equivalent
<u>Ptarmigan</u>				
P1	P	2	-2.8 to -3.8	4.6 - 6.3
	S	3	-4.6 to -5.7	7.4 - 10.4
P3	P	1	-3.2	5.4
	S	2	-7.5 to -8.5	11.1 - 12.3
P4	P	2	-4.5 to -5.2	7.3 - 8.2
	S	2	-6.1 to -9.2	9.4 - 13.1
P5	P	1	-1.4	2.3
	S	3	-8.8 to -16.3	12.7 - 19.8
<u>Tom</u>				
T1	P	1	-3.2	5.4
	S	3	-6.5 to -7.9	9.8 - 11.6
T3	P	2	-3.6 to -3.8	5.9 - 6.3
	S	3	-15.0 to -19.2, +183	18.7 - 31
T4	P	2	-2.4 to -2.6	3.9 - 4.2
	S	2	-8.8 to -13.4	12.7 - 17.2
<u>Tin</u>				
S1	P	2	-2.1 to -4.4	3.5 - 7.1
	S	3	-7.2 to -12.3	10.7 - 16.3
S2	P	2	-2.7 to -3.4	4.4 - 5.6
	S	3	-6.5 to -10.2	9.9 - 14.2
<u>TA</u>				
D1	P	2	-2.5 to -3.4	4.1 - 5.6
	S	3	-5.3 to -12.5	8.4 - 16.4
D4	P	2	-2.4 to -3.7	3.9 - 6.1
	S	3	-6.5 to -9.2	9.8 - 13.1
D5	P	2	-4.4 to -7.5	7.0 - 11.1
	S	3	-7.7 to -14.5	11.4 - 18.3
D6	P	1	-3.0	4.9
	S	2	-4.8 to -5.0	7.6 - 7.9
D8	P	2	-1.9 to -2.9	3.1 - 4.8
	S	2	-5.6 to -5.9	8.7 - 9.1
<u>Hidden Lake</u>				
H1	P	2	-2.8 to -3.7	4.6 - 6.1
	S	3	-4.6 to -8.4	7.4 - 12.2
H2	P	1	-3.5	5.8
	S	2	-6.5 to -12.7	9.8 - 16.7

Locality and Sample Number	Inclusion Class	Number Measured	T _m ^o C Range	Wt.% NaCl Equivalent
H3	S	3	-5.5 to -7.5	8.6 - 11.1
H5	S	2	-3.7 to -6.0	6.2 - 9.3
H6	P	2	-2.0 to -4.4	3.4 - 7.1
	S	2	-6.7 to -8.6	10.2 - 12.4
H7	P	2	-3.2 to -11.2	5.2 - 15.2
	S	2	-6.2 to -9.2, +134	9.5 - 29
H9	S	2	-5.7 to -5.9	8.9 - 9.1
H11	P	1	-3.0	4.9
	S	3	-6.8 to -11.1	10.3 - 15.1

Negative T_m values are of T_m ice.

Positive T_m values are of T_m NaCl.

APPENDIX IV

FLUID INCLUSION HOMOGENIZATION DATA

Locality and Sample Number	Inclusion Class	Number Measured	Th ⁰ C Range	Remarks
<u>AM</u>				
A1	primary	5	209-231	One vapour phase inclusion
	secondary	6	107-121	
A2	P	8	213-270	
	S	4	121-144	
A3	P	3	251-253	
	S	6	212-168	
A5	P	6	212-240	
	S	7	126-201	
A6	P(?)	2	211-221	
	S	4	139-151	
A7	P	5	239-267	
	S	8	155-210	
A8	P	3	224-235	
	S	5	122-136	
A10	P	4	253-264	
	S	6	111-148	
A11	S	5	129-134	
A12	P	3	285-301	
	S	7	129-151	
A14	P	1	310	
	S	4	149-170	
<u>Camlaren</u>				
C1	P	2	302-308	VG
	S	4	112-151	
C2	P	3	250-264	
	S	5	141-202	
C3	P	2	272-286	VG
	S	3	139-148	
C4	P	4	219-243	
	S	5	129-161	
C5	P	1	245	VG
	S	6	132-161	
C6	P(?)	1	227	
	S	3	113-141	
C8	P	3	234-256	VG
	S	3	117-121	
C9	P	5	224-274	
	S	6	125-176	

Locality and Sample Number	Inclusion Class	Number Measured	Th ⁰ C Range	Remarks
C10	P	3	212-274	VG, 1 vapour phase inclusion
	S	6	131-170	
C11	P	4	237-280	
	S	5	124-182	
C12	P(?)	2	205-283	
	S	4	137-173	
C13	P	4	233-264	
	S	5	139-181	
<u>Joon</u>				
J1	P	2	263-268	
	S	4	121-141	
J2	P	3	261-291	VG
	S	5	136-149	
J3	P	5	233-281	One vapour phase inc.
	S	6	131-153	
J4	P	4	212-276	VG
	S	4	131-160	
J5	P	2	239-248	VG
	S	5	137-181	
J6	P	4	244-273	
	S	4	123-131	
J7	P	1	314	One vapour phase inc.
	S	3	122-143	
J8	P	3	261-289	
	S	5	111-139	
J10	P	3	253-281	
	S	4	107-136	
<u>Ruth</u>				
R2	P	3	203-276	
	S	4	160-180	
R3	S	3	178-210	
R4	P	2	283-291	
	S	4	113-138	
R6	P	3	232-245	VG
	S	5	126-161	
R7	P	2	245-322	One vapour phase inc.
	S	4	122-135	
R8	P	3	213-251	
	S	3	131-164	
R9	P	2	244-267	
	S	5	121-182	
R10	P	2	233-250	
	S	4	116-153	

Locality and Sample Number	Inclusion Class	Number Measured	Th ⁰ C Range	Remarks	
<u>Ptarmigan</u>					
P1	P	3	293-315	One vapour phase inclusion	
	S	5	108-133		
P3	P	1	243		
	S	4	111-157		
P4	P	4	262-301		
	S	5	126-186		
P5	P	3	237-288		
	S	5	143-202		
<u>Tom</u>					
T1	P	2	254-296		
	S	6	103-142		
T3	P	4	201-281		
	S	6	117-183		
T4	P	4	263-294		
	S	5	123-214		
<u>Tin</u>					
S1	P	3	281-305		
	S	5	131-193		
S2	P	5	243-322		
	S	6	118-173		
<u>TA</u>					
D1	P	4	221-283		One vapour phase inc.
	S	6	121-175		
D4	P	3	291-331	VG	
	S	5	126-162		
D5	P	3	264-294	VG	
	S	6	135-202		
D6	P	2	273-289		
	S	5	116-180		
D8	P	3	263-286		
	S	4	121-198		
<u>Hidden Lake</u>					
H1	P	3	225-285		
	S	6	115-165		
H2	P	2	264-271		
	S	4	126-152		
H3	P	1	293		
	S	5	109-151		
H5	S	3	135-147		

Locality and Sample Number	Inclusion Class	Number Measured	Th ^o C Range	Remarks
H6	P	4	241-311	One vapour phase inclusion
	S	5	118-164	
H7	P	3	264-325	
	S	3	125-146	
H9	S	4	131-180	
H11	P	2	309-314	
	S	6	117-183	

P = primary

S = secondary

Th = temperature of homogenization

VG = visible gold

B30315